The Simple Facts about Sampling Gold Ores
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ABSTRACT
Various approaches are used in the industry for establishing procedures (sample mass estimation and method of subsampling) for sampling and analysis of gold ores. The key factors that determine the accuracy of the results that can be expected for a given set of procedures are widely misunderstood.

Recent developments in sampling theory show that the estimation of the accuracy that can be expected for a given gold ore as a function of sample mass is actually a simple matter. For a given sample mass, the accuracy that will be achieved depends only on the grade of the ore and the range of masses of the grains of the gold in the ore. This, of course, demands that a reasonable estimate of the distribution or spread of gold grain masses in the ore be known. But this is something that should be known if the gold is to be efficiently recovered in the processing plant.

This paper provides a simple explanation of the real facts about sampling of gold, either in the field or in the plant, and provides results for a number of cases of combinations of fine and coarse gold in an ore. The prerequisites for accurate gold sampling are:
• correct sampling with no loss of sample or contamination
• sample preparation procedures that recognise the impact of the gold grain mass spread
• practical analysis of the sample masses required to provide acceptable accuracy.

Issues of corporate governance are also discussed.

INTRODUCTION
There has been a large effort put into the development of theory and practice for the definition of sampling protocols for gold ores. Gold ores are perhaps the most difficult to deal with in terms of finding a set of sampling procedures (protocols) at various stages of size reduction of the ore and run-of-mine (ROM) material. There is a certain air of mystery about the test work required to define the protocols and the analysis of the test work to arrive at a final set of procedures and sample masses that must be retained at each stage of sampling, be it ROM, reverse circulation (RC) chips or core. The battle between various viewpoints has been going on for many years without any clear reconciliation of the various viewpoints.

Gy’s sampling theory has been applied in an approximate fashion in these efforts (1982). A closer look at his theory and the development of some new computational methods which can provide the entire sampling distribution for a gold ore can demystify the whole issue, from sampling of coarse ore down to the required analytical aliquot that is needed to control the analytical uncertainty due to the heterogeneity of the comminuted sample. This approach can be expanded to take into account the dilution of ore by barren material.

François-Bongarçon, Minnitt and Pitard and their co-authors have all contributed over the years to the methodologies proposed to determine the mass of sample that must be retained at each stage of sampling and sample preparation. All the work has been based on Gy’s simplified formula for sampling variance. It turns out that the simplified formula as set out fully in Appendix 1 and recalled below is over simplified as it is not the size of the particles themselves that control the sample variance and distribution but the mass distribution of the gold particles in the ore coupled with the impact of dilution of the ore by coarse barren particles.

The accuracy achieved in the sampling of a gold deposit has serious ramifications in relation to corporate governance. It first impacts the resource estimation regardless of whether the modelling is geostatistical or a more deterministic interpolation. It then impacts the ore-waste interface determination which effectively sets the value of the mineral resource when coupled with an expected recovery figure. What level of accuracy (we hope the sampling is unbiased) is acceptable for a gold deposit: five per cent, ten per cent, 20 per cent or 30 per cent? What should the Competent Person (CP) allow when passing judgement on the work that has been done? How well do we understand the impact of the accuracy on the final valuation of the ore?

In the subsequent sections of the paper, the application of Gy’s simplified formula will be considered and then a series of examples of the impact of the gold particle mass distribution and size distribution of barren particles will be illustrated and compared with the simplified Gy approach. The issues of drilling for resource definition and grade control are central to achieving accuracy as this is what provides unbiased samples.
and controls sample mass. This issue together with the concern for governance concludes the paper.

GY’S SIMPLIFIED FORMULA

Gy’s simplified formula for the variance of the sample assay \( a_s \) is of the form:

\[
\text{var} \left( \frac{a_s}{a_s^2} \right) = \frac{K_s}{M_s} = \frac{1}{M_s} \cdot \text{cf}_g \cdot d_{95}^2
\]

(1)

where:

- \( K_s \) is the sampling constant for the material
- \( M_s \) is the sample mass
- \( c \) is the mineralogical factor
- \( f \) is the particle shape factor
- \( g \) is the size distribution factor

The full development of Gy’s simplified formula for the sampling variance is reviewed in Appendix 1 where it is demonstrated that the formula cannot capture sufficient detail about the nature of the mineralisation to provide useful estimates of the sampling variance. The reason behind this failure is the substantial difficulty in finding a value of the so-called ‘liberation factor’, \( f \), for an ore. Since the publication of his book in English (Gy, 1982), attempts to model the variation of the liberation factor as a function of the sample top size have been in the form:

\[
f = \left( \frac{d}{d_{95}} \right)^\beta
\]

(2)

where:

- \( d \) is a liberation particle size
- \( d_{95} \) is the 95 per cent passing size of the ore sample under consideration
- \( \beta \) is an exponent

However, as is shown in Appendix 1, this form is simply not a good model for the variation in the sampling variance over a wide range of particle sizes, even for ores that can be expected to be easy to model. The interpretation of \( f \) as a liberation factor is also flawed. The simplified formula fails because it does not consider the ore structure or texture in sufficient detail. Gy never intended that this formula should be universally applied.

Gy’s more detailed expression (see Appendix 1) for the sampling variance has better potential, but is still difficult to apply, especially in the case of gold ores.

THE CONTROLLING FACTOR OF SAMPLING VARIANCE FOR GOLD-BEARING MATERIALS

The fact is that the control on sampling variance is the number and mass of the gold grains that are captured in the sample together with a secondary, but usually minor, influence of the size distribution of barren material in the sample. This control acts not just in samples of crushed or ground gold ore; it operates in the core samples recovered from the orebody itself.

Consider a process of decomposition of the ore that frees the grains of gold-bearing species (electrum or relatively pure gold or any other mineralogical association giving rise to particles of nominally constant gold content) within particles and that permits determination of their distribution by mass. This information should be defined for a given geological domain as it influences both the processing of the ore and the manner in which sampling should be carried out for both resource modelling and grade control. The worst-case situation should be considered (coarsest gold distribution); this is most important in veined and stockwork deposits where coarse gold is common.

With this information, it is possible to determine the sample masses that are required to control the magnitude of the uncertainties associated with the sample assays to a level that limits to a reasonable level the risk associated with decisions based on those assays.

The most important concepts behind understanding the sampling of gold ore are:

- the distribution by mass of the gold grains controls the sampling uncertainty associated with a sample of a given mass
- the number of gold grains of any one mass falling into a correct sample follows a Poisson distribution and this is the driver that controls the overall shape of the sampling distribution
- the sampling distribution is controlled by the number of gold grains whether those grains are liberated or not.

Figure 1 shows two samples taken from a lot of gold ore. The sampling is carried out correctly, so the sampling is unbiased. Whether the gold grains are liberated or not, the expected gold contents of both samples will be the same and the sampling variance will be the same in each case.

It is also true that as sample preparation continues, the sampling constant, \( K_s \), will not decrease with the cube of the particle top size; it will be a very weakly decreasing function of the particle top size. A significant decrease in the sampling constant will take place only when the gold grains within the sample are broken into smaller fragments; their liberation from the host rock is immaterial. Breakage of gold grains is a difficult process due to the malleability of gold in native metal (gold or electrum) form.

GOLD SAMPLING EXAMPLES

Coarse gold

Recent development of sampling statistics (Lyman, 2014) has permitted the calculation of sampling distributions rather than just the sampling variance as provided by the work of Gy (1982). This work considers both the size distribution of barren material in the sample and the distribution of either locked or liberated particles carrying the target phase or element. It is ideal for the application to the sampling of gold ores and has been used in the design of a metallurgical accounting sampling plant and sample preparation and analysis protocol in which sampling of ROM other party’s ore had to be implemented. The final result for the system was a weekly composite analysis estimated to have a 95 per cent confidence interval of two per cent relative for a grade of nominally 2 g/t.

\[ \text{FIG 1} – \text{Nominaly identical subsamples from a gold ore with liberated and locked gold particles.} \]
Consider a gold ore carrying both coarse and fine generations of gold with the mass distribution by size shown in Figure 2. The +150 micron gold is 25 per cent by mass. The grade will be taken to be 2 g/t.

Applying the new method for calculation of the sampling distribution, the grade distribution for 5 kg samples is as given in Figure 3, for a 12.5 mm top size of the ore. There is an upwards skewness of the distribution. A 3 kg sample of this ore at 12.5 mm top size would have a relative standard deviation (RSD) of 11.3 per cent. To reduce the RSD to two per cent, the sample mass required would be 95 kg.

Now reduce the particle size to 2 mm top size; this will not lead to any breakage of the gold, so the sampling constant for the material will be reduced only very slightly (to 37.6 g) due to the reduction in the top size. However, if the size distribution of Figure 2 was a result of some clustering of the gold leading to effectively larger grains, the reduction in the top size may reduce the sampling constant for the ore.

Now reduce the entire 5 kg sample to -150 microns so that the +150 material effectively falls into the distributions below 150 microns. The comminution of the sample may not guarantee that all large gold grains will be broken down as they may simply flatten and smear. However, if the breakage is achieved, 1 kg subsamples of the ore will follow the distribution shown in Figure 4.

Finally, if 1 kg subsamples are pulverised to -75 microns, the distribution of 50 g samples will be as shown in Figure 5. The RSD is 5.97 per cent and the sampling constant is 0.178 g. The mass distribution of gold grains by size is shown in Figure 6. This distribution is quite fine, but the RSD due to heterogeneity of the gold is larger than the uncertainty attached to a fire assay, which should be between one and two per cent relative. We find 30 g aliquots carry an RSD of 7.70 per cent.

Consider what will happen if the sample preparation protocol involves the following:
- collection of a 5 kg sample with crushing to 12.5 mm
- crushing to 2 mm
- division of the 5 kg to 1 kg
- pulverisation of the 1 kg to -75 microns
- division for 50 g fire assays.

The variance components involved are provided in Table 1.
The magnitude of the total variance is distressing and is due primarily to the fact that the gold particles cannot be broken by crushing to 2 mm. One may argue that the first variance component can be removed as the original sample is the lot from which reduction is made. This lowers the overall RSD to 18.25 per cent, but this is still a large figure.

The answer to the problem of reduction in assay variance is to recognise that sample mass should not be reduced just because the top size has been reduced. Ideally, the whole 5 kg should be leached in a device similar to the PAL (pulverise and leach) system from Mineral Process Control of Perth. That machine can handle 1 kg of sample in each leaching pot and 52 pots can be used in each run of about one hour. Ten 5 kg samples with two controls can be used in a run. -12.5 mm material will be ground to about -75 microns and leached in that time. There are no smearing problems as flattened gold grains will simply dissolve. The solids from the leach can be recovered, washed and sent for fire assay to correct for any unleached encapsulated fine gold. Allowing a two per cent RSD for the corrected leach value and two per cent for the assay of the gold in the leach liquor, the total RSD is 2.8 per cent. Sample preparation other than crushing and splitting is eliminated. The cost per sample, excluding the analysis of the liquor, is just under A$4 for a fully occupied in-house system (amortisation of equipment, consumables, labour and overheads) and 1 kg samples.

**Gold clustering**

The clustering of gold grains as can be expected to occur in veined deposits is an important issue in understanding and quantifying the heterogeneity of a gold ore. When clusters result in impressive visible gold on core surfaces, the determination of optimal sampling protocols for gold require more than simply defining the maximum grain size of the metal. The heterogeneity tests that have been proposed by Pitard and François-Bongarçon then become useful, not for the purpose of calibrating the model based on Gy’s simplified formula (the K-ρ model), but for detecting the clustering itself and providing guidance for a sampling protocol.

Minnitt, Rice and Spangenberg (2007) and Spangenberg (2012) have published data that permits investigation of this clustering effect. The Minnitt data set involved collection of about 35 kg of sample from a plant feed which was crushed to -25 mm, 3 mm, 1 mm and 0.5 mm as per the scheme described in Appendix 2. Here, 30 of the 32 subsamples formed for each top size were assayed for gold, with the remaining two subsamples analysed for size distribution. The average grade and the grade variance were as shown in Table 2. The observed variance was corrected for an analytical RSD of four per cent. From the relative variance, an estimate of the effective top size of the gold grains within the crushed sub samples was estimated using $f = 0.5$, $g = 0.25$ and $\rho_{tie} = 19.0$ using the analysis of Appendix 2. The results for the estimated top sizes for the gold are entirely reasonable.

The corresponding data and calculations for the data from Spangenberg (2012) are provided in Table 3. The 95 per cent passing sizes for both data sets are plotted in Figure 7. It is clear that the two ores used by Minnitt, Rice and Spangenberg (2007) are virtually identical. This fact has been confirmed by Spangenberg (private communication, 2016). The critical factor here is that these two independent investigations of an ore produced results that are entirely compatible, suggesting that the methodology for analysis of the ore heterogeneity proposed here is correct.

**Gold ore heterogeneity data from Spangenberg (2012).**

<table>
<thead>
<tr>
<th>Step</th>
<th>$K_i$</th>
<th>Relative standard deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in mass from a very large lot to 5 kg</td>
<td>38.1</td>
<td>$RSD = 100 \sqrt{\frac{K_i}{\text{S}} - 1} = 100 \sqrt{\frac{38.1}{5000} - 1} = 8.73$</td>
</tr>
<tr>
<td>Reduction in mass of -2 mm material to 1 kg</td>
<td>37.6</td>
<td>$RSD = 100 \sqrt{\frac{K_i}{\text{S}} - 1} = 100 \sqrt{\frac{37.6}{1000} - 1} = 17.3$</td>
</tr>
<tr>
<td>Reduction in mass of -75 micron material to 50 g</td>
<td>0.178</td>
<td>$RSD = 100 \sqrt{\frac{K_i}{\text{S}} - 1} = 100 \sqrt{0.178\frac{1}{50} - 1} = 5.82$</td>
</tr>
<tr>
<td>Total relative standard deviation</td>
<td></td>
<td>20.23</td>
</tr>
</tbody>
</table>

**Gold ore heterogeneity data from Minnitt, Rice and Spangenberg (2007).**

<table>
<thead>
<tr>
<th>Top size [mm]</th>
<th>25</th>
<th>3</th>
<th>1</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average grade</td>
<td>12.95</td>
<td>12.68</td>
<td>13.04</td>
<td>12.41</td>
</tr>
<tr>
<td>SD of grade</td>
<td>4.94</td>
<td>1.07</td>
<td>0.73</td>
<td>0.58</td>
</tr>
<tr>
<td>Variance of grade</td>
<td>24.38</td>
<td>1.15</td>
<td>0.53</td>
<td>0.34</td>
</tr>
<tr>
<td>Relative variance</td>
<td>0.14528</td>
<td>0.00714</td>
<td>0.00313</td>
<td>0.00218</td>
</tr>
<tr>
<td>Relative standard deviation (RSD)</td>
<td>0.381</td>
<td>0.085</td>
<td>0.056</td>
<td>0.047</td>
</tr>
<tr>
<td>Analytical relative variance</td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0016</td>
</tr>
<tr>
<td>Corrected relative variance (RSD')</td>
<td>0.1437</td>
<td>0.0055</td>
<td>0.0015</td>
<td>0.0006</td>
</tr>
<tr>
<td>Nominal subsample mass [g]</td>
<td>273</td>
<td>273</td>
<td>273</td>
<td>273</td>
</tr>
<tr>
<td>$K_i$ [g]</td>
<td>39.22</td>
<td>1.51</td>
<td>0.42</td>
<td>0.16</td>
</tr>
<tr>
<td>$d_{10%}$ [microns]</td>
<td>598.1</td>
<td>200.6</td>
<td>132.0</td>
<td>93.7</td>
</tr>
</tbody>
</table>

**Gold ore heterogeneity data from Spangenberg (2012).**

<table>
<thead>
<tr>
<th>Top size [mm]</th>
<th>19</th>
<th>12</th>
<th>4.75</th>
<th>1.18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average grade</td>
<td>8.88</td>
<td>8.28</td>
<td>8.86</td>
<td>8.66</td>
</tr>
<tr>
<td>SD of grade</td>
<td>3.55</td>
<td>2.58</td>
<td>1.18</td>
<td>0.64</td>
</tr>
<tr>
<td>Variance of grade</td>
<td>12.59</td>
<td>6.63</td>
<td>1.39</td>
<td>0.41</td>
</tr>
<tr>
<td>Relative variance</td>
<td>0.160</td>
<td>0.0967</td>
<td>0.0177</td>
<td>0.00553</td>
</tr>
<tr>
<td>Relative standard deviation (RSD)</td>
<td>0.400</td>
<td>0.311</td>
<td>0.133</td>
<td>0.0744</td>
</tr>
<tr>
<td>Analytical relative variance</td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0016</td>
</tr>
<tr>
<td>Corrected relative variance (RSD')</td>
<td>0.1583</td>
<td>0.0951</td>
<td>0.0161</td>
<td>0.00393</td>
</tr>
<tr>
<td>Nominal subsample mass [g]</td>
<td>276</td>
<td>192</td>
<td>266</td>
<td>233</td>
</tr>
<tr>
<td>$K_i$ [g]</td>
<td>43.68</td>
<td>18.26</td>
<td>4.27</td>
<td>0.915</td>
</tr>
<tr>
<td>$d_{10%}$ [microns]</td>
<td>546.5</td>
<td>399.3</td>
<td>251.6</td>
<td>149.4</td>
</tr>
</tbody>
</table>
These two examples taken from the literature suggest that sampling properties of gold ores should be based on estimates of the gold grain mass distribution by size. There is a great deal more data in the literature that can be analysed this way. Where clustering of gold grains is suspected in a veined ore, heterogeneity tests can be used to estimate the top size of the gold grains/clusters and to provide the actual sampling constant for the material at a given top size. Use of the simplified G̱y formula and calibration of the model proposed by François-Bongarçon is unnecessary and probably obscures the nature of the gold occurrence in the ore as a result of the confusion in regard to the liberation factor which does not actually reflect real gold liberation. Working in an effective top size sheds more light on the texture of the ore and its processing properties.

**The Process of Sampling and Analysing Gold Ores**

Prior to planning an exploration program, it is necessary to arrive at a worst-case estimate of the gold grain size distribution, so that sampling and sample preparation protocols can be established, at least in a preliminary manner. Next, the tolerable uncertainties for the assays must be established. Should the RSD be 15 per cent, ten per cent, five per cent, two per cent or what? What will be the impact of the RSD on the block estimation for the geological domain? With the larger RSDs, the nugget variance in the variogram will make it more difficult to define the spatial correlation in the deposit and the assay variances will propagate through to the block estimation variance resulting in increased smoothing of the interpolated block grade. Using non-geostatistical methods (radial basis functions or inverse distance etc), the error propagation to the block estimates may be even worse.

What follows is mainly concerned with exploration and grade control sampling, but in dealing with the sampling of process streams in the concentrator, the role of the gold grain size distribution does not change, so it becomes very important to understand how the grain size varies within the circuits and whether sampling must account for sampling loaded carbon particles.

**Drilling**

The most basic level of sampling of the ore is sampling by drilling – most commonly by sampling of conventional blastholes (BH), diamond coring (DC) or RC drill sampling – or by collection of a sample from channel sampling or bulk sampling. Especially in the case of drilling, it is first necessary to determine the level of uncertainty that can be tolerated, technically and economically, in the sample results. For a given intersection length, doubling the diameter of the hole will produce four times the sample mass and cut the average sampling standard deviation in half. This result is of course contingent upon the recovery of all the material, including dust from the RC hole drilled. For the sampling to be mechanically correct, and therefore unbiased, full recovery and elimination of contamination is mandatory. Similarly, with full recovery, the mass of sample must be sufficient to provide the accuracy needed.

In all cases, the barren material contained in the sample simply dilutes the ore derived from a single geological domain and this is easily taken into account. Two or more ore types in a domain can also be dealt with. The critical information required in such a case is the distribution by mass of the gold grains in each ore type, at a worst case (coarsest distribution), and an estimate of the mass proportions of the ore types and barren material.

Table 4 shows the sample mass that can be used with half DC or with RC drill bits on 1 m intervals. The RSDs for a fine and medium gold size distribution are also shown in the table. In each case the top size of the comminuted sample is 4 mm. The gold size distributions are shown in Figure 8.

In calculating the precisions of sampling involved, the intrinsic heterogeneity of the content of the hole or half core have been assumed to apply to the sample as this heterogeneity will show up in the variogram calculated from the sample data (see discussion in Appendix 4).

The data in Table 4 indicate that the heterogeneity associated with even 12 kg samples is significant for the gold size distributions used in the calculations.

**Preparation and analysis of samples**

The data of Table 4 indicate that to limit the uncertainty associated with gold ore samples, the analysis should employ sample masses as large as practical. This limit is probably around the 10 kg point. Samples of 10 kg can be readily analysed as 1 kg subsamples using the PAL system as mentioned earlier. The PAL system eliminates much of the sample preparation as -12 mm material can be directly charged to the pots and ground to -75 microns in the course of the analysis. Low-grade samples can be dealt with as the analysis ideally involves extraction of the precious metals (including Pd and Pt) into an organic phase such as methyl isobutyl carbinol or diisobutyl ketone, which also eliminates iron interference in atomic absorption (AA) analysis. Inductively coupled plasma

<table>
<thead>
<tr>
<th>Sample mass for 1 m length (kg)</th>
<th>Fine gold precision (1.96σ) [%]</th>
<th>Coarse gold precision (1.96σ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>27</td>
<td>0.77</td>
</tr>
<tr>
<td>BQ</td>
<td>36.4</td>
<td>1.41</td>
</tr>
<tr>
<td>NQ</td>
<td>47.6</td>
<td>2.40</td>
</tr>
<tr>
<td>HQ</td>
<td>63.5</td>
<td>4.28</td>
</tr>
<tr>
<td>PQ</td>
<td>85</td>
<td>7.66</td>
</tr>
<tr>
<td>RC 5½ in</td>
<td>133</td>
<td>37.7</td>
</tr>
<tr>
<td>RC 5½ in</td>
<td>140</td>
<td>41.4</td>
</tr>
</tbody>
</table>
GOVERNANCE ISSUES

Unlike most industries, the foundation for the exploration, mining and extractive industry is based on sampling, especially particulate material. Once a bias is introduced at any stage of the sampling process the error propagates through all subsequent processes contributing to the uncertainty of the end result and any decision derived therefrom.

ASX Listing Rules and Guidance Note 31 (ASX, 2013) reference the JORC 2012 Code, a normative document setting the minimum standards for Public Reporting in Australasia of Exploration Results, Mineral Resources and Ore Reserves. Transparency, materiality and competence are the guiding principles. JORC (2012) Table 1 provides a checklist upon which a Competent Person (CP) must provide commentary on the material assumptions underlying the Declaration of the results or on an ‘if not why not’ basis. The CP is bound by the Australian Institute of Geoscientists or AusIMM Code of Ethics and take full responsibility of the statements in the Declaration of the results. The CP providing commentary on sampling must have recognised expertise in sampling and provide evidence that the samples and subsamples at any stage represent the in situ material collected. The company conducting the sampling must have quality assurance policies, sampling procedures and protocols in place as well as enforced and monitored to verify the data is fit for the purpose. There tends to be a laissez-faire approach by those performing sampling to blindly follow a protocol and not continually monitor the performance of quality control (QC) samples on receipt for each sample batch to meet a data quality objective, a ‘tick and flick mind set’, or leave the analysis of the QC samples to the end of a project. This may result in time delays to the project to remedy, significantly adding to the cost.

The reference in Table 1 under Sampling Techniques to ‘industry standard’ work presents a conundrum as one size fits all approach to sampling may not generate subsamples that are representative as defined in this paper.

A sampling procedure and protocol fit for purpose can be established by an orientation study at the commencement of a project when samples become available and pre-engagement of a laboratory (Long, 2007; Hoogvliet, Grieve and Sims, 2014).

There appears to be an industry mindset that DC is superior to RC drill chips considering recommendations to twin RC drill holes with DC. Now that a Progradex sampling system is available to collect 100 per cent of the sample passing through the inner tube, a cost-effective alternative to drill core is at hand. These RC samples provide a larger volume of sample, which more effectively samples mineral clusters, that better represents the in situ ore and does it faster and cheaper than diamond drilling. Poor sampling practices may result in increased resource risks (Vann et al, 2014) that come to light when the project is developed. Failure of projects developed by equity funding may require further dilutive capital depressing the share price. Projects developed in part or whole by bank funding are subject to bank completion tests whereby the performance of the project as a whole over a period (eg three months) is assessed by an independent engineer or independent technical expert (McIntyre, 2011). The continuing performance will be monitored over the loan term period to ensure the bank’s cover ratios are not breached, ensuring the project has sufficient value for the bank to cover the residual value of the loan if in default. Sampling at all stages from the mineral resource, mining reserve, grade control and metallurgical accounting is paramount to this process.

Company executives, in their relentless pursuit to reduce costs often give directives to slash costs by an arbitrary percentage (ten per cent, 15 per cent, 25 per cent) with no consideration of the impact on the quality of samples, are more likely to unknowingly destroy more shareholder value than that achieved by reducing the direct costs. Contract managers tender drilling and laboratory contracts on the basis of three quotes, often selecting the lowest price tender as best value; this has several adverse knock-on effects. The tender documents generally lack clarity in the required accuracy fit for the purpose on which the contractor can price their bid. Contractors with the best quality equipment that is designed to take correct samples will be out bid by contractors with cheaper likely incorrectly designed sampling equipment and operating practices. The result is that sampling equipment that the manufacturer designs to collect correct samples will be driven out of the market by cheaper products (Pitard, 2014). Contract drilling companies and commercial laboratories are operated as profit centres and produce a service/product that the client will accept. The end result is that the sample may not be representative of the minerals of interest in the ground. Inappropriate sample masses and sample preparation used by a low cost laboratory may lead to an accuracy that is not fit for purpose, leading to the suboptimal development of the resources. Low accuracy increases the uncertainties in the definition of ore and waste boundaries, incurring ore loss to waste heaps and high costs associated with hauling and processing waste at the expense of displacing ore. Companies may become aware of sampling problems when performing a Mine to Mill reconciliation process (Parker, 2012). In the worst case geologists may suffer analyses paralysis through lack of

optical emission spectroscopy / mass spectrometry can also be used as a finish, delivering accurate analyses.
time to monitor and react to sample quality control metrics, compounding the situation in a time of stress.

Companies may be advised by corporate advisers who recommend key performance indicators to monitor the performance of the organisation. Frequently, the number of holes and metres drilled is recommended as a performance metric to monitor the efficiency of a geology department or geologist for performance payments set by human resources departments or for setting annual salaries. These metrics may be a proxy for how much capital a company is prepared to spend in the ground on the assumption the more drilling the more likely a resource discovery will be made. Metres drilled is not a measure of the quality of the work performed by a geologist or driller. The end result non-conforming product is likely to be generated faster destroying further shareholder value. Metrics based on quality of samples are more appropriate to demonstrate that samples are fit for purpose.

Commercial arrangements for mutual benefit to process ore may be entered into, either by a junior company without processing facilities or a processor to extend their plant operational life as their own ore is depleted or not being mined at a sufficiently high rate or the plant throughput constrained by hard deeper ore as soft oxide ore may be depleted to sustain a high plant throughput to maintain reduced costs. These relationships are complex, not only technically but also managing a good working relationship between the parties, taking the entire sampling process to a higher level of accuracy than expected by a processor processing their own ore. Maintaining cash flow over a short term is critical for the junior company to stay in business, more so if the project is bank funded by the junior company and the bank protecting its interest.

A transparent, accurate, accountable and traceable process is essential to the success of such commercial arrangements. This can be achieved by formation of a technical committee, with equal representation by each party to jointly manage the technical aspects of the arrangement but not economic, commercial or financial which remain under the control of each party who can direct their representative how to vote. The technical committee can be advised by technical experts at technical committee cost, or each representative advised by a technical expert at the cost of the party or if mutual agreement cannot be made within a specified limited time, that can be varied by agreement of the technical committee to maintain production, the issue to be referred to an independent expert for determination, the cost allocated by the independent expert. The technical committee can respond to changing conditions experienced as mining progresses drawing on experience gained as part of a quality assessment process. It is important that technical procedures are generated and agreed as part of negotiations between the parties and the technical procedures to form legally binding attachments to the body of the legal document. The attached legal documents are living documents that can be changed only by agreement of the technical committee and can be referred to by an independent expert. The establishment of an intranet and document management system controlled by the technical committee is essential for display of agreed procedures and protocols for the operators to comply with so there is no confusion with the version or the owner’s operating practices. Each party to have intranet access to data and information at any time on approved privilege basis to minimise the perception or otherwise data is being manipulated or withheld. Dispute resolution by an independent expert is recommended to minimise potential legal action that most likely will arise from a sampling issue.

It is essential that grade control sampling be performed by RC drilling, best on an appropriately oriented staggered grid covering sufficient multiple benches to allow time for the receipt of gold assays and checking that each batch passes the appropriate QC checks at each stage, especially at each sample size reduction, flagging non-compliant batches to be reprocessed where appropriate. The QC checking can be automated to pass predetermined algorithms before up loading to a database. RC and BH rigs can be fitted with sensors to record in real-time the rate of penetration, torque, as well as other parameters so that rock mass 3D models can be generated to aid in blast design to minimise fragment top size. It is recommended the use of blast movement monitors to establish post blast ore boundaries to minimise dilution and ore loss (Isaaks, Barr and Handayani, 2014).

To achieve a higher accountability and tracking it is recommended ore be place on bed blend finger stockpiles (Everett, Howard and Jupp, 2015) that are closed off before the systematic loading of ore, progressing along the stockpile toe direction as built into road trains using a loader equipped with a weighing device certified for trade purposes. This prevents stockpiles becoming error accumulators commonly experienced with loading stockpiles on a last on last off principle.

Batching ore through a processing plant has major sampling issues accounting for changes in gold-in-circuit as plants are mostly not compliant with AMIRA 754 Code for metallurgical accounting (AMIRA, 2007). The process is disruptive to stable processing, inhibiting optimising the processing to reduce costs. The smaller the batches of ore the greater the impact the change in gold-in-circuit becomes.

Blending ores from various sources and with other party’s ore to optimise a plant is always contentious unless an independent determination by a purpose built gold sampling plant is made. Attempts to determine the quantity of product produced by each party or mine or ore stockpile, generally in a month, based on mine to mill reconciliations is fraught with difficulties associated with accounting for variable ore movement during blasting and ore loss to waste heaps. Each ore type will have a different sampling variance that is not accounted for in the reconciliation process.

Any attempt to short cut the sampling process to save costs is likely to result in considerable management time wasted trying to reconcile the irreconcilable with a hostile party.

CONCLUSIONS

With the advent of a method for calculating the entire sampling distribution for a gold ore as a function of the mass distribution of the gold grains as a function of size, much of the mystique of sampling gold ore is dispelled. It is of course a challenge to determine the gold grain size distribution, but the heterogeneity tests previously used to calibrate Gy’s simplified formula can be used in a different way to detect clustering of gold and to detect the effective top size of gold in the ore. Making a reasonable assumption regarding the overall size distribution of the gold grains, a robust sampling protocol can be devised.

However, it is clear, from the calculations presented herein, that there is a large advantage attached to the analysis by accelerated leaching methods using the PAL system of large samples up to 10 kg, or even more in critical cases. This method eliminates a good deal of sample preparation and, in particular, removes the uncertainties attached to the smearing of gold during comminution and produces more accurate analyses in short time frames and at comparable or lower cost than traditional fire assay or screen fire assays.
Exploration and grade control drilling can now take advantage of new sampling technology from Progradex to capture mechanically correct, unbiased samples from RC drill rigs which produce larger samples faster and at a lower cost than traditional DC methods. RC drilling can precede BH drilling, the material from the latter providing only very poor samples.

Using these advances in sampling theory and technology, corporate governance in the gold industry can be substantially improved with cost saving as well.

REFERENCES


Lyman, G, 2011. In situ and particulate material heterogeneity, in Proceedings 5th World Conference on Sampling and Blending, Santiago, Chile, pp 3–21 (Gecamin: Santiago).


APPENDIX 1 – RELATION BETWEEN FY’S FULL AND SIMPLIFIED FORMULAE

Gy’s simplified formula for the variance of sampling is based on his fundamental formula for the sampling variance, which has the form:

$$\frac{\text{var} \{\bar{x}_j\}}{\text{var} \{x_i\}^2} = \frac{K_S}{M_S}$$  

(3)

where:

- $K_S$ is the value of the sampling constant for the material
- $M_S$ is the nominal mass of the sample
- $\bar{x}_j$ is the nominal sample assay with respect to the target analyte
- $\text{var} \{\bar{x}_j\}$ is the variance of the assay

The square root of the equation provides the relative standard deviation (RSD) the sampling uncertainty due to the intrinsic heterogeneity of the material. The sampling constant is given by:

$$K_S = \sum_{i=1}^{N_S} \sum_{j=1}^{N_f} y_i \rho_i \left( \frac{\bar{x}_j - a_j}{a_j} \right)^2$$  

(4)

The quantities involved in the formula are provided in Table A1. The effective particle volume for the $i^{th}$ size fraction is:

$$v_i = f_i d_i^3 + d_i^2$$  

(5)

where:

- $f_i$ is a particle shape factor
- $d_i$ is the sieve aperture defining the upper limit of the size fraction

The formula can also be written as:

$$K_S = \sum_{i=1}^{N_f} v_i H_i$$  

(6)

where:

$$H_i = \sum_{j=1}^{N_S} y_i \rho_i \left( \frac{\bar{x}_j - a_j}{a_j} \right)^2$$  

(7)

This last term is called the intrinsic heterogeneity (IH) of the $i^{th}$ size fraction because it quantifies the heterogeneity of the material with respect to the target analyte. Figure A1 shows the
mass fraction, $y_{ij}$ as a function of the size fraction ($i$ subscript) and composition class ($j$ subscript) for a mineral sample.

Figure A2 illustrates the calculation of the terms involved in the calculation of the IH value for a size fraction as they relate to the mass distribution by concentration of the particles in a mineral sample. With reference to Figure A1, it is clear that as the distributions of particles spread towards the ends of the concentration axis, the IH value for the size fraction will increase.

Gy’s simplified formula for the sampling constant as defined here is:

$$K_S = c f g d_{95}^l$$  \hspace{1cm} (8)

where:
- $c$ is a mineralogical composition factor
- $f$ is the shape factor
- $g$ is the size distribution factor
- $l$ is the liberation factor
- $d_{95}$ is the screen aperture which 95 per cent of the particles pass

The mineralogical composition factor is simply a value of the maximum possible IH value that can occur for the target analyte.
mineral and the remainder of the minerals. This value is found by assuming that the sample consists of particles of the pure target mineral and particles that are barren with respect to the target mineral. This leads to a value of $c$ for all size fractions of:

$$c = \frac{1}{\rho_{\text{p}} a_i - 1}$$

(9)

The value of the sampling constant can then be written as:

$$K_s = \frac{1}{\rho_{\text{p}} a_i - 1}$$

(10)

where:

$$\eta_i = \frac{d_i^{1.5} + d_{i-1}^{1.5}}{2d_i^{1.5}}$$

(11)

The summation term in Equation 10 is then written as:

$$\sum_{i=1}^{N_k} x_i \eta_i \frac{\rho_{\text{p}}}{\rho_{\text{p}} a_i - 1} = g^\ell$$

(12)

where the distribution of the particles over the size fractions is the primary contribution to $g$ and the values of $\rho_{\text{p}} a_i$ are the primary contribution to $\ell$. The value of $g$ runs from close to 1 for a very narrowly sized material to about 0.25 for a typically encountered size distribution. The value of $f$ is generally close to 0.5.

So the final outcome is Equation 8. All the terms except $\ell$ can be calculated with ease.

If $\ell$ is to be associated with $\rho_{\text{p}} a_i$, note that the value of $\ell$ cannot decrease as the top size of the material is decreased as this would imply that the target mineral is becoming less liberated as the material is comminuted.

Now return to the basic formula (Equation 8) and consider what happens if the sampling variance does not decrease with material top size at constant sample mass and a value of the liberation factor is back-calculated as was done for the data presented by Carrasco et al (2005), which is reproduced in Figure A3. The fact that the sampling variance is not decreasing means that $K_s$ is constant, so:

$$\ell = \left( \frac{d_i}{d_{95}} \right)^{f^\ell}$$

(13)

The term in parentheses is effectively a constant, so it appears that $\ell$ is a strong function of material top size and strongly increasing as material top size decreases! But it has just been deduced that $\ell$ is not increasing and is otherwise nearly constant.

One is then forced to conclude that a back-calculated value of $\ell$ from experimental sample data is not a liberation factor at all. It is just a factor in the formula reconciling the actual sampling variance with the material top size in the simplified formula.

With reference to Figure A3, the plot for disseminated and veined molybdenite at the larger particle sizes with slopes of about -3 indicate that the molybdenite is not liberating at all until the top size gets to about 200 to 300 microns. Then the slope decreases sharply indicating that liberation is actually taking place.

For the disseminated chalcopyrite, the flat curve down to about 1.5 mm, indicates that some liberation is taking place and then this liberation decreases down to 250 microns where further liberation takes place. The veined chalcopyrite shows a similar effect.

A model for the variation of $\ell$ with the 95 per cent passing size of the sample material has been proposed and pursued, most often by François-Bongarçon and particularly for gold ores.

The suggested model is:

$$\ell = \left( \frac{d_i}{d_{95}} \right)^{f^\ell}$$

(14)

where $d_i$ is a so-called liberation size of the target mineral phase. The value of the liberation constant will be unity when $d_{95} = d_i$. 
It is interesting to take the central part of the plots and extrapolate the curves to the value of \( t = 1 \). For the copper ore, the liberation sizes appear to be 15 and 140 microns for the veined and disseminated ores respectively and 48 and 58 microns for the disseminated and veined molybdenum ores respectively. One would expect the veined Cu ore to have a larger liberation size than the disseminated ore, but this is not the case. For the Mo ores, the liberation sizes appear to be similar while it would be expected that the disseminated ore would have a liberation size substantially smaller than the veined ore.

If the left-most parts of the curves are extrapolated, all the ores have vanishingly small (submicron) liberation sizes.

It is abundantly clear that the model - Equation 14 - is of very little utility for the estimation of the sampling constant for an ore over a wide range of particle top sizes and that the apparent value of the liberation size has no physical basis and indeed the interpretation of the value of \( t \) as a liberation factor is essentially nonsense in a general case.

For gold ores and other ores where the target analyte is carried as blebs of very high-grade mineral (for example, isoferronplatinum Pt, Fe), even Gy’s full Equation 4 is difficult to apply. The correct model for the statistics of sampling is then a weighted sum (or integral) of Poisson distributions for each mass class of the grains carrying the target analyte. Lyman’s (2014) method implements such a calculation and allows for the size distribution of barren particles as well.

An approximation to the sampling variance can be found using Equation 4 by focussing on the gold grain size distribution alone. In such a case, if \( y \) is the mass fraction of grains having mass \( m = \rho y \), then \( x = \bar{a} y \), and the sampling constant can be written as:

\[
K_S = \sum_{i=1}^{N_S} \frac{\bar{a}_i y_i \rho_i}{\bar{a}_S} \left( 1 - \frac{\bar{a}_i}{\bar{a}_S} \right)^2
\]  

(15)

Now the summation is over the gold grain size distribution and all particles in that distribution have \( \rho = \rho_{Au} \) (all have the gold density of about 19 g cm\(^{-3}\)), so:

\[
K_S = \rho_{Au} \bar{a}_S ^2 \sum_{i=1}^{N_S} \frac{y_i}{\bar{a}_S} \left( 1 - \frac{\bar{a}_i}{\bar{a}_S} \right)^2
\]  

(16)

If the grade is some g/t the concentration term is:

\[
\left( \frac{\bar{a}_i - \bar{a}_S}{\bar{a}_S} \right)^2 \approx \left( \frac{1 - \bar{a}_S}{\bar{a}_S} \right)^2 \approx \frac{1}{\bar{a}_S^2}
\]  

(17)

Introducing a particle shape factor \( f \) for the gold and a size distribution factor \( g \) for the gold distribution:

\[
K_S \approx \frac{\rho_{Au} \bar{a}_S}{\bar{a}_S} fg^{4 \times 95}_{\bar{a}_S}
\]  

(18)

Where the particle size, \( \bar{a}_S \), now refers to the gold and not the sample as a whole.

For simple size distributions of fine gold, this expression is a reasonable approximation. Pitard and François-Bongarçon (2011) introduced this expression without derivation indicating that it was to be used when the gold was liberated; it has been demonstrated that the gold need not be liberated.

**APPENDIX 2 – HETEROGENEITY TESTS AND GOLD CLUSTERING**

A procedure proposed by François-Bongarçon (see Minnitt, Rice and Spangenberg, 2007) involves collection of nominally 45 kg of the ore under study and crushing of that ore to 19 mm top size (95 per cent passing). A subsample of \( 1/4 \) of the -19 mm material is put aside and the remainder crushed to 12 mm top size and a subsample of \( 1/4 \) of is retained while the remainder is crushed to 4 mm. Half of this material is retained and the rest crushed to 1 mm. The sequence of top sizes can be varied but should cover the range of sizes encountered in the normal or planned processing of the ore.

Each of the four subsamples are then divided into 32 nominally identical subsamples and each of those subsamples are very carefully prepared for assay by the chosen method (fire assay, accelerated cyanide leach, neutron activation etc). If the analysis procedure involves the extraction of a subsample of the material produced by the 32-way split, the material should be ground very finely before extraction of the analytical aliquot to minimise the heterogeneity of the aliquot. Ideally, the entire mass of each of the 32 subsamples should be analysed (fire assay to extinction or leaching of the full subsample).

The mean grade and grade RSD over the 32 subsamples for each top size are then determined from the results. The RSD over the 32 subsamples may be corrected for the uncertainty associated with the analysis procedure itself if this variance is separately established with confidence. These data can then be used in the procedure proposed by François-Bongarçon to calibrate a model based on Gy’s simplified formula as discussed in Appendix 1 or can be used to assess the extent to which gold grain clustering may be present in the ore.

Lyman (2014) has demonstrated that the variance of gold content between nominally identical subsamples of an ore depends only on the mass distribution by size of the gold grains when the subsample mass is substantially larger than the mass of the coarsest particles in the subsample. For a gold grain size distribution with a maximum size of some hundreds of microns (say 400 microns), comminution to a top size of some mm will not break the gold particles. There may be some breakage of gangue away from the gold, but the gold mass distribution will not change until there is real breakage of gold particles (which is difficult due to the gold malleability). However, if the gold particles in a veined ore cluster together and the top size is reduced to close to the size of the clusters, the clusters may be broken apart and this will cause a change in the effective grain size of the gold. Until broken apart, the clusters act as large gold grains from the point of view of the ore heterogeneity.

If the corrected RSD of the subsamples is found to be a decreasing function of the top size of the gold ore, this indicates that the effective size distribution of the gold is decreasing (see Equation 18) and this can only come about if there is breakup of gold grain clusters. Using Equation 18, an indication of the top size for the gold can be estimated:

\[
RSD = \frac{\sigma}{\bar{a}_S} = \sqrt{\frac{K_S}{M_S}}
\]  

(19)

So:

\[
\frac{\rho_{Au} \bar{a}_S fg^{4 \times 95}_{\bar{a}_S}}{M_S} = \frac{K_S}{M_S}
\]  

\[
d_{95}^{\bar{a}_S} = \left[ \frac{M_S \times \bar{a}_S \times RSD^2}{fg^{4 \times 95}_{\bar{a}_S}} \right]^{1/3}
\]  

(20)
APPENDIX 3 – ISSUES IN USE OF SAMPLES FROM DRILLING AT VARIOUS STAGES OF A MINE DEVELOPMENT

Conventional blasthole sampling

Perceived advantages
• The tight drill patterns provide shorter range information than previous exploration drilling
• in-pit drilling activity is minimised
• it is considered that the holes serve the dual purpose of blasting and sampling.

Actual reality
• Vertical blasthole (BH) direction likely to be unfavourably oriented orthogonal to mineralisation increasing sampling variance
• blasthole grid pattern likely to be unfavourably oriented to the mineralisation continuity anisotropy increasing sample preparation and analytical costs
• the sample interval may include the sub-bench sample interval
• poor and inconsistent recovery from the hole – especially during hole collaring – making the drilled interval subject to error; problems of hole caving, erosion and recovery
• suffers from cross-contamination due to hole caving and erosion
• not suited to drilling in wet ground
• fines are lost to ground voids and to atmosphere as material exits the hole and upgrading of the sample by dust extractors for dust control winnowing sample fines
• the large volume of material from the hole makes correct (unbiased) sampling effectively impossible
• the large number of samples produced in each blasthole drilling campaign may overwhelm the capacity of especially an on-site laboratory leaving no time for effective quality control, forcing production to continue using information from an above-mined bench or resource drilling data
• mine planning is reactive, tying production, laboratory and processing schedules together
• contributes to high stress levels in the workforce, contributing to a higher employee turnover.

Coring

Advantages
• Drill site has small footprint minimising environmental damage and remediation cost
• correct sampling provided that full core recovery is achieved
• core can be oriented spatially in 3D for rock mass characterisation including establishing paragenic relations and providing sample billets for mineralogical, geotechnical and metallurgical breakage studies
• in situ bulk densities can be measured for weighting each sample increment for resource estimates
• deep hole drilling is possible.

Disadvantages
• Coring in broken ground may require more expensive larger diameter core and triple tube drilling techniques to achieve higher core recoveries
• core drilling in swelling ground may require special mud to achieve higher recoveries
• small relative volume of material constrained by costs may result in unrepresentative samples due to too few gold particles being sampled, limiting the accuracy of assay data
• relatively slow and expensive drilling restricting closer drill spacing constrained by budget
• high post core processing costs incurred by cost of core trays for storage, cutting core by a diamond saw and coarse crushing core prior to fine crushing and pulverising
• no duplicate field samples are available as half or quarter cores are spatially separated; half or quarter cores submitted for sampling are generally accepted as a proxy for duplicate field samples.

Reverse circulation sampling (with bottom face sampling hammer)

Advantages
• Reverse circulation (RC) drilling provides a larger volume of sample than drill core in a shorter time at substantially lower cost
• drilling process keeps water out of the samples and dry
• holes angled favourably orthogonal to mineralisation decreasing sampling variance
• grid pattern favourably oriented to the mineralisation continuity anisotropy reducing sampling variance and laboratory costs
• sample size yields fit for purpose data when used in conjunction with a correct sampling system
• sample turnaround is much lower than core providing critical geostatistical evaluation data fast
• chip sizes are relatively small and consistent
• RC drill rig can be equipped with sensors that can achieve higher recoveries
• RC drill rig can be equipped with sensors that can

Disadvantages
• Large drill site footprint limiting its use in mountainous terrain
• limited to relatively shallow holes (~500 m) or limited by water head
• recovery in poor ground conditions may be inadequate
• must be used with a correct sampling system
• potential exposure of operators to dust bearing hazardous minerals (fibrous minerals) if rig is not equipped with a correct sampling system.

Traditional sampling systems for an RC rig include a cyclone, a collection vessel below it and some type of splitter below this to split the sample down to a manageable bag sample.
to be sent to a lab for processing (be it by riffle, cone, Vezin or derivatives of these). Various adaptations of this gravity feed concept have been developed over the past 20 years but they all lack the single most important premise of sampling – mechanical correctness (lack of bias). The reason is that none of them fully collect the fines for sampling and so cannot be correct and unbiased.

Some might suggest that, while not perfect, results without the fines should be adequate. That is to assume on no bases of testing that the fines do not significantly influence true assay and can therefore be deemed negligible to the overall result. It is also assumed that the splitters themselves used in a gravity fed system both homogenise and split a bulk sample correctly.

Professor Ana Carolina Chieregati of the University of Sao Paulo in Brazil recently undertook an evaluation of the Progradex sampler. This sampler collects both coarse and fine material and spreads it in layers, a form of bed blending using a rotating tube at the cyclone discharge to produce a layer cake. Fines from the filters are dropped on these layers every few seconds. Finally, this layered material is dropped over a pair of pie shaped sampling ports to which sample bags are attached. There is 100 per cent solids collection from the drill hole. Sample bags can be indexed past the sampling ports to make separate collection of drilling intervals.

Chieregati assessed the sampler against the suite of possible sampling ‘errors’ defined by Gy as shown in Figure A4 and concluded that the sampler is mechanically correct and consequently delivers unbiased samples. Other authors have noted the advantages of RC grade control and of the Progradex sampler in particular (Reid, in-press; Pitard, 2008; Goers and Almond, 2012; Day, 2014).

The grouping and segregation error (GSE) is cancelled by the layering of the material accomplished by the rotating tube. The weighting error (WE) does not come into play as the total flow of solids from the hole pass through the sampler. The delimitation and the extraction errors (IDE and IEE) are cancelled as the total flow is sampled in a mechanically correct manner (radial cutters). The preparation error (IPE) depends entirely on the correctness of the sampling protocol but will add to the variance due to the fundamental sampling error (FSE) associated with the particulate heterogeneity of the material coming from the drill bit and the mass of sample removed for each drilling interval. The final analytical error will depend on the method of analysis and the mass of the analytical aliquot and its particulate heterogeneity.

REFERENCES


APPENDIX 4 – FIELD DUPLICATE SAMPLES

There is much discussion in regard to the duplication of samples at the field level, the coarse crush level and the pulp level, and other levels as well that may be present in the sample preparation protocol. The duplicates are considered necessary to determine the level of precision that is achieved in the drilling program.

When coring, the best duplicate that can be had is the other half of a half core, where the general assays in the program are being based on half core. This definition of a duplicate is debated by many as they state that the two halves of the core differ, sometimes even visibly. While such differences are very real, it is simply impossible to get a better duplicate while the core is in the solid form; the same hole cannot be drilled twice. It is unavoidable that there will be a difference in the true mean assays of the two halves due to the local texture (small-scale variability) of the ore (Lyman, 2011). Knowledge of the difference is however of value, especially in the geostatistical context, as the average variance between

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**FIG A4** – Cancelling of all sampling errors other than the fundamental sampling error (FSE), courtesy of Prof Ana Carolina Chieregati, University of Sao Paulo, Brazil.
half core assays should be equal to the nugget variance of the variogram for the geological domain from which the core was taken.

In attempting to use field duplicates for tracking of sampling precision, there are two ways in which the data from the duplicates can be generated and analysed. If both samples are prepared and analysed according to the protocol employed for all other samples, the variance between them will be the sum of the in situ variance in grade and the sample preparation and analysis variance. If the protocol is a poor one with large variance components due to insufficient sample mass, the in situ variance will be swamped and will not be discovered.

On the other hand, if the duplicate samples are prepared and analysed with a special protocol which is designed to reduce the preparation and analysis variance to very small levels, the in situ variance may be discovered correctly. The method to be used depends on the objective of the exercise.

For RC drilling, field duplicates are readily available as the RC drill is likely to produce more sample per interval than is needed to achieve acceptable precision so that the RC sample for the interval can simply be divided down in mass to provide two nominally identical subsamples of the mass called for in the protocol. Indeed, the sampling system attached to the rig may provide the duplicates directly.

Obviously, in this case, the in situ variance between half cores is absent and the duplicates are true duplicates.

There is a final matter to be considered in relation to field duplicates and that is whether or not the intrinsic heterogeneity of the primary sample should be included in the assessment of the overall sampling variance for the drilling program. When a core is taken, it is the 'lot' from which subsamples will be derived and, in principle, it has zero variance. However, it is well recognised that it does indeed have a variance and that variance is the true geological nugget variance or in situ variance for the ore at the scale of the core sample. If the assays of the core were perfect, this variance would show up on a variogram.

However, when the core is crushed and divided down in mass, the intrinsic heterogeneity of the crushed material comes into play.

For an RC sample, the in situ heterogeneity at the scale of the hole is destroyed and replaced by the particulate heterogeneity of the RC chip sample. However, if the preparation and analysis of the RC sample is ‘perfect’, the variogram calculated from the assays will still show the in situ heterogeneity at the scale of the hole.

APPENDIX 5 – DEFINITION OF ‘REPRESENTATIVE’

The term representative is widely used in reference to samples and sampling. It is, however, a term that is poorly defined in practice. Broadly, if a person considers a sample or procedure to be acceptable (by some standard of their own definition), they add the tag, representative. This vagueness attached to the word is not satisfactory when used within a regulatory document.

The authors consider the use of the following constraints upon the use of the term to be mandatory.

A sample must first be unbiased, meaning that it has been extracted in a mechanically correct manner. For sampling from a process flow, this means that it has been taken from the flow with no delimitation or extraction error and its integrity (no loss or contamination) has been preserved after extraction. Subsequent stages of sample preparation must also be mechanically correct. For sampling by drilling, an unbiased sample must include only and all that material that is part of the cylindrical volume defined by the drill. The drilled sample is then mechanically correct. Samples from holes that cave or from which there is loss of core, chips and/or fines are not unbiased.

A sample must secondly be such that the results from its assay are fit for the purpose to which the results will be put. The best example of fit for purpose is a sample used to determine the value of a consignment of concentrate sold to a client. There will be a contract of sale associated with the transaction which will specify that the range of metal contents contained will fall into certain ranges and deviation from that specification will be subject to penalties or bonuses. Both the buyer and the seller wish to avoid a situation wherein the probability of underpayment or over payment based on the sample assays for the consignment is large enough to cause either party to be out of pocket for a significant period of time. They want the assay results to be unbiased and accurate. The accuracy needed is measured relative to the terms of contract. The sample and its analysis will be fit for purpose if the risk of unacceptable over or underpayment meets with satisfaction of both parties.

The fit for purpose part of the constraint on the use of the term representative is therefore defined by the circumstances at hand. A process control sample may still be fit for purpose when it is significantly less accurate than a sample used for commercial transactions.

Prior to the establishment of any sampling protocol, the users of the data must define the accuracy that will make the data fit for purpose.