Grade Control in Open Pit Gold Mines – The True Cost of Sampling Blast Holes

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INTRODUCTION

It is becoming widely accepted throughout Australia and in other parts of the world that sampling of open blast holes for grade control in open pit mines usually produces poor quality, biased sample grades. The quality of samples taken from blast holes is impacted by the generally poor sample recoveries achieved by this drill type. The problem is more serious when sampling for trace elements that naturally give rise to positively skewed sample populations, such as gold, uranium, and contaminant elements such as phosphorous in iron ore deposits.

Poor sample recoveries are not unique to open hole drilling. However, for more sophisticated drilling techniques (e.g. reverse circulation drilling), sample recoveries can be monitored and improved through better drilling equipment and techniques. This is not true for open hole blast holes.

Any interpretation of ore outlines based on poor quality sample data (regardless of the drilling density) will produce sub-optimal results and contribute significantly to misclassification of ore to waste and waste to ore, resulting in significant financial loss to operations.

OBJECTIVES OF GRADE CONTROL

The primary purpose of grade control in any open pit gold mine is to provide an efficient discrimination between material that is above economic cut-off grade (ore) and that which is below cut-off grade (waste). A secondary but important goal is to provide reliable estimates of the gold grade that will be achieved in mining. These are two different issues for grade control but optimizing the first usually resolves the second.

The efficiency of any ore selection system is critically dependent on:

- Quality of sampling and assaying.
- The way in which sample grades are used to predict the grade of mining volumes.
- The level of selectivity achieved by mining and blasting practices.

Errors in any one of these processes detract from the efficiency of the ore selection process.

Errors arising in the collection, preparation and assaying of samples inevitably lead to misclassification of ore to waste *and* waste to ore. The situation is analogous to driving in city traffic with a frosted windscreen. Sampling and assaying bias also lead to misclassification of ore and waste but is likely to lead to much greater losses than result from other sampling errors. The driving analogy would now include a driver with glasses which make other vehicles look further away then they actually are.

Errors in the process used to predict mining grades from sample grades may result in misclassification of ore as waste *and* waste as ore. For example, a process of block grade estimation that does not adequately respect the dispersion variance of metal grades (i.e. an estimation procedure that smoothes grades) will misclassify some ore as waste and some waste as ore. Bias in the ore grade estimation process will misclassify ore as waste *or* waste as ore. For example, it has been well demonstrated that mining to polygonal outlines interpreted around sample assays almost inevitably results in mining to a higher cut-off grade than is intended.

All ore-waste misclassification always leads to financial loss. The cost of misclassification decreases with increasing sample density but increases with increasing cut-off grade.

Overall, the optimization of ore selection is not merely choosing a good grade estimator, which may be for example a polygonal method with an upper cut to the assays, or ordinary kriging with or without predefined geological constraints. The principal objective of an optimized grade control is to maximize the financial return from short-term mining of a bench, taking into account the related costs of sampling and the cost of misclassification of ore and waste.

GENERAL COMMENTS ON SAMPLING

In gold sampling, significant errors are often incurred both in the extraction and collection of pulverized material from the drill hole and in the way samples are split from the material in the field. It is generally observed that between 70 and 95 percent of the material is extracted from RC hollow-hammer drill holes as chips to be sampled. Often less than 60 percent is collected from blast holes. For both drilling methods, a proportion of the material is lost as fine dust. This fine material is often not sampled but it is assumed that the gold grade of this material is the same as that of the chips. This assumption is rarely tested but where sampling of the dust has been undertaken the assumption has been found to be unreasonable.

The sampling system used to split the grade control sample from the cyclone-collected material is often poorly designed and operated. Multi-tier Jones riffle splitters are commonly used. They are often under-sized or have incorrectly sized slots for the volume and particle size of the sample to be split, resulting in overflowing, choking of the splitter, and uneven flow of the material though the splitter.

Laboratory procedures for splitting of the pulp are often questionable. Personnel working in sample preparation are usually the least skilled of laboratory staff. They may be poorly trained or unmotivated to use proper methods of sample extraction to minimize grouping and segregation errors, which are implicit to gold sampling due mainly to potential for gravity segregation.

Many mines do not have routine procedures for monitoring and reporting of sampling and assaying quality. This is a major shortcoming in the maintenance of efficient production.

DRILL HOLE LOCATION AND ORIENTATION

Blast holes usually cannot be angled to optimally intersect ore-grade structures. The primary purpose of blast holes is to optimize rock fragmentation with minimal movement of the in situ material. Dedicated grade control drill holes allow the orientation of sampling to be customized to different mineralized areas. Holes should be drilled in the direction of weakest continuity of grade, i.e. across strike and dip if practicable.

Similarly, spacing of blast holes is designed to optimize rock fragmentation whereas dedicated grade control drill holes can be set out to optimize sample spacing for ore definition. In most gold orebodies the optimum sample spacing is broader than the optimum blast pattern.

Planning of an area to be drilled for grade control sampling is a critical part of the mine grade control procedure. It requires a good understanding of the disposition of mineralisation and commitment to review all the information to ensure the drill holes are optimally sited. One of the problems in current grade control procedures is the segregation of the pit floor into areas for blasting. In some areas the mineralised zones are in close proximity to blast boundaries or transect two or more blast patterns. On other occasions poor pit scheduling results in internal temporary batters/access ramps being placed in areas of high-grade ore. In both situations, significant ore grade material is lost.

QUALITY OF BLAST HOLE SAMPLING

Blast hole sampling has several major shortcomings. The major shortcoming is the most obvious one: blast holes are drilled to make a hole in the ground; RC sample holes are drilled to recover a sample from the ground.

Not all the material from blast holes is available for sampling. The loss of sample comprises an uncontrolled reduction of sample mass and almost always leads to sample bias by preferential loss of fines. Much of this loss is unobserved as pulverized material is lost into sub-floor joints and cracks opened by previous blasts. Loss of fines is often worse with wet, open hole drilling.

Drill cuttings are generally not cleared as efficiently from blast holes as they are from RC drill holes because of the larger annulus between drill rods and the wall of the hole and resultant lower up-hole air velocity. This can lead to “trailing” of pulverized material down holes, producing down-hole contamination.

Because blast holes are normally drilled by open-hole techniques, pulverized material must contact the wall of the hole on its way to surface. This provides a means of sample contamination, particularly in friable materials such as partially weathered rock.

At most mines using blast hole samples, grade control personnel collect the samples from blast hole rigs fitted with vacuum dust collectors and splitters. This equipment uses a fan mounted at the rear of the drill rig to induce an air vacuum to pick up the comminuted material from the drill collar through a rubber boot at the foot of the drilling boom. The material then passes across a small cyclone and the larger and higher density particles collect in the closed cyclone. The remaining smaller sized particles continue to pass the cyclone and are collected by filter pads in a dust collector at the rear of the drill rig. Periodically this collected dust is expelled onto the ground when the airflow ceases (e.g. rod changes). At the end of each sample interval the base of the cyclone is opened and the material dumped through a riffle splitter and approximately 1/8 is split into a calico bag for assay.

There are a number of problems with this sampling system that, in general, result in poor quality sub-samples. In most mines there is no significant improvement in the quality of the sample from a dust collector system compared to a scoop sampling system from blast hole rigs. The problems with dust collector systems include:

- The vacuum hose does not pick up any damp material.
- A large volume of the finer grained material is lost to the dust filters resulting in segregation of the material. The coarser grained material is preferentially retained by the cyclone.
- As the cyclone fills up during the sample interval there is a greater loss of material to the dust collector.
- Vacuum hoses are regularly partially occluded by the build up of material within the hose, particularly where the hose is sub-horizontal along the rig length. This causes cross contamination of samples.
- The dumping of the sample through the small riffle splitter results in overflowing, choking or blocking of the riffles, leading to biased splitting.

- The system does not overcome the major problem of poor sample return from the blast hole.

H&S, through involvement with the gold mining industry over many years, has accumulated substantial evidence suggesting that in the majority of cases samples from blast holes are biased and unrepresentative of the mineralisation being sampled. H&S has many examples to show that, when tested, grade control sampling from blast holes leads to significant misclassification of ore and waste and results in reduced profit for the mining operation. Four case studies are described below.

STUDY 1: SAMPLE SEGREGATION AND LOSS

A test programme, undertaken at a hard rock gold mine where the gold is contained within quartz veins, collected samples from each 2.5 metre down-hole interval including:

- The normal 3 kg split from the cyclone collected material.
- All reject material split from the cyclone collected material.
- The dust from the dust collector.

The blast holes were each five metres deep plus one metre of sub-drill, drilled by Tamrock rigs fitted with a dust collector system and integrated cyclone and riffle splitter.

The results showed that material collected at the cyclone was on average 60 percent of the mass of the material theoretically available from the drilled interval. Ten percent of sample mass was lost to the dust collector and 30 percent was lost down-hole. The test also showed that the first sample in each hole had less than 50 percent of the mass of the second sample collected, and that the grade of the dust was very different to the grade of the split sample. In one area tested, the dust reported an average grade that was 50 percent lower than the average grade of the split sample. It was concluded that if the poor sample return and grade bias for this bench was consistent for all blast holes, then the split samples (used for ore outline generation) from the top mining bench were overstating the grade of in situ mineralisation by 20 percent.

The study also indicated that the splitter used on the blast hole rig was not consistently splitting the sample from the cyclone. For some holes it was taking a 1:5 split and on other occasions it was a 1:7 split. This is not uncommon for blast hole rig-mounted cyclones and splitters that tend to be undersized for the amount of sample obtained, prone to blockage, subjected to physical agitation, and often not operated in a level position because of drilling on uneven ground.

STUDY 2: SAMPLE LOSS AND BIAS

Another case study based on sampling from Tamrock 1000 blast holes measured the sample loss down-hole and though the dust collector. Results showed that 35 percent of material from an interval was lost down-hole, 30 percent was lost through the dust collector, and the cyclone only collected 35 percent of the theoretical mass of each sample interval.

A disturbing finding was that the grade of the dust was, on average, only half that of the split sample. On average, the sample split for assay was overstating gold grades by 20 to 25 percent due to measured dust losses alone. This does not consider the material losses down-hole which were likely to further increase the bias in the sample grade.

STUDY 3: BLAST HOLE SAMPLES VERSUS RC SAMPLES

A recent study by H&S on a comparison between RC and Blast Hole sampling at a Western Australian gold mine provides further evidence on the losses incurred by relying on blast hole sampling. In this study, sixty 5m deep blast holes were paired with RC holes collared within 0.5m of the blast holes. The pairing of holes allowed a statistical comparison of both the global grades and on a "grades by depth" intervals. Samples from each drilling technique were assayed by fire assay at the same laboratory.

Figure 1 shows the scatter plot of data pairs over all grade ranges. The broad scatter on this plot indicates poor correlation of pairs that were within 0.5m of each other. A large cluster of data pairs is evident where 1 to 2 g/t Au BH assays are paired with 0.5 to 1.5 g/t Au RC assays (circled area on plot). There are significant differences between the two sample types at lower grade ranges.

Figure 2 shows a quantile-quantile plot of grades of RC-BH shown for the entire range of sample grades. It is clear that at different grade thresholds the relationship between the histograms of gold grades changes.

Figure 3 shows a QQ plot grade range of 0.3 to 3.0 g/t Au. This is a relevant range for gold grades in grade control because this is where the decision to mine material as either ore or waste is made. This plot clearly shows that the histogram of the RC FA grades is significantly different to that of the BH FA grades. The percentage difference varies with changing grade. At the lower grades i.e. 1.0 g/t Au the BH grades are approximately 20 percent higher whilst at 2.0 g/t Au the difference is 10 percent.

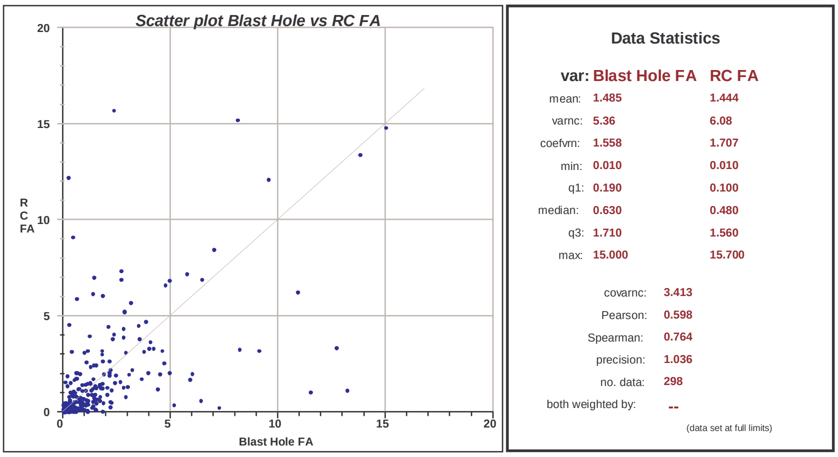

Figure 1: Scatter Plot of RC and Blast Hole Fire Assay pairs over all grades

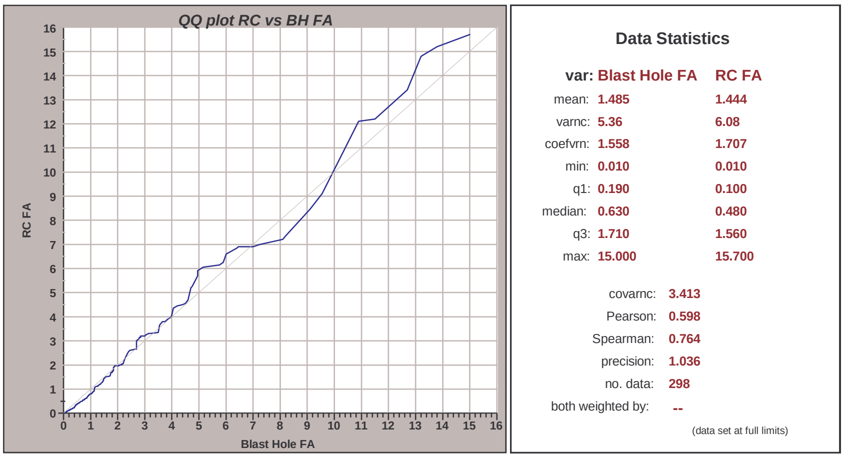

Figure 2: QQ plot of RC and Blast Hole Fire Assays over all grades

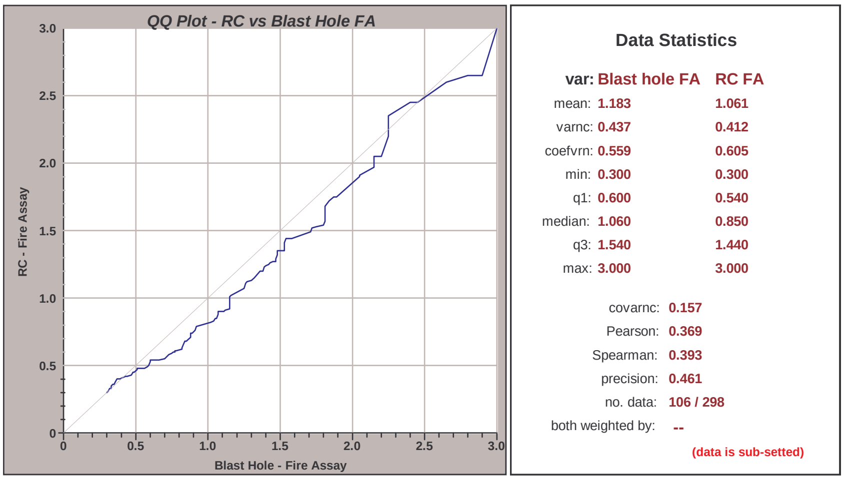

Figure 3: QQ plot of RC and Blast Hole Fire Assays between 0.3-3.0g/t Au.

Figures 4 to 8 show quantile-quantile plots comparing samples for each down-hole sample interval. The comparison at grades less than about 2g/t is most important; above this grade the comparisons are over an insignificant number of samples.

In most sample intervals there is clearly a bias to higher grades in blast hole samples. This is particularly apparent in the 0-1m and 4-5m sample intervals, i.e. the first and last sample intervals in each hole. We expect that in blast holes the first sample interval is greatly affected by sample loss at the hole collar and the last sample interval is affected by down-hole contamination.

The bias varies with sample interval in a quite unpredictable way.

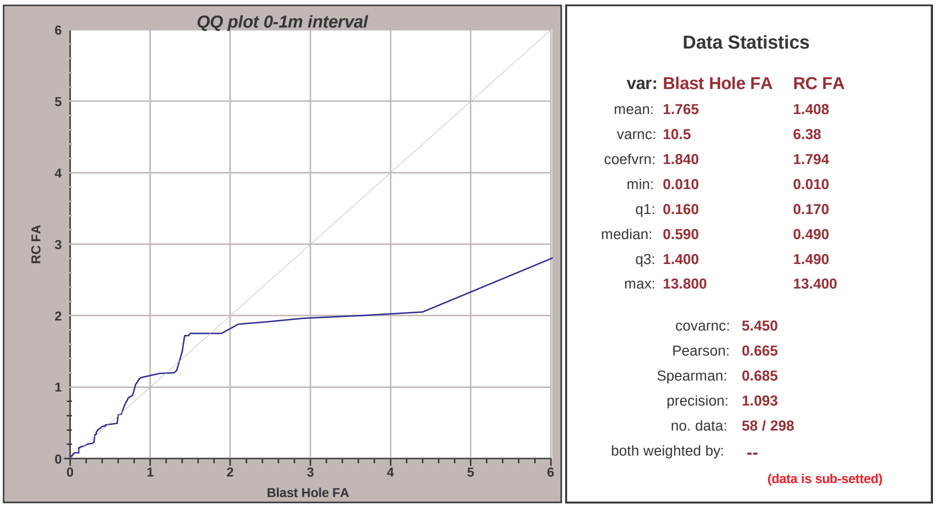

Figure 4: QQ plot RC-BH FA for 0-1 m interval

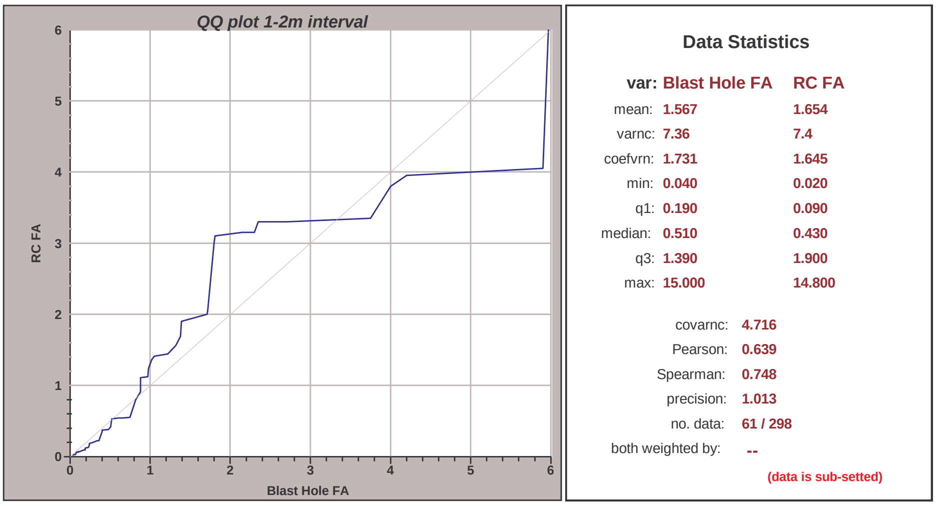

Figure 5: QQ plot RC-BH FA for 1-2 m interval

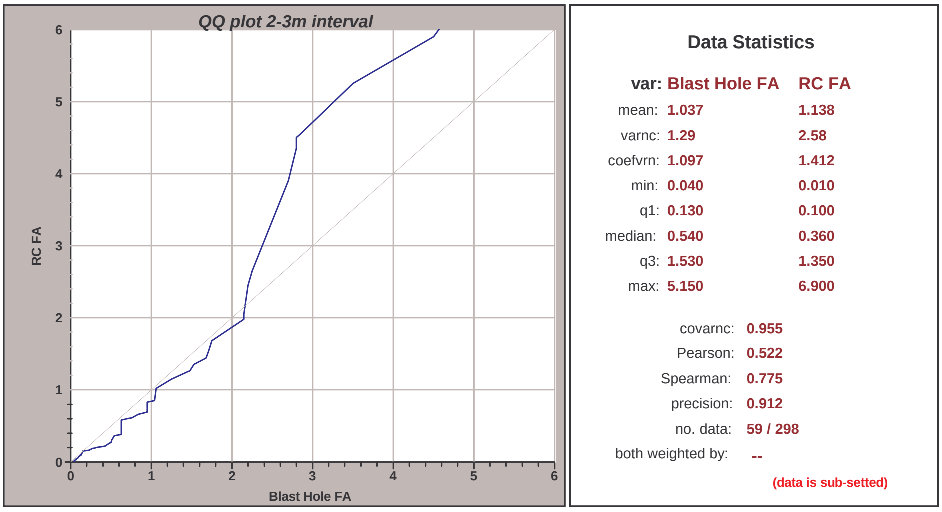

Figure 6: QQ plot RC-BH FA for 2-3 m interval

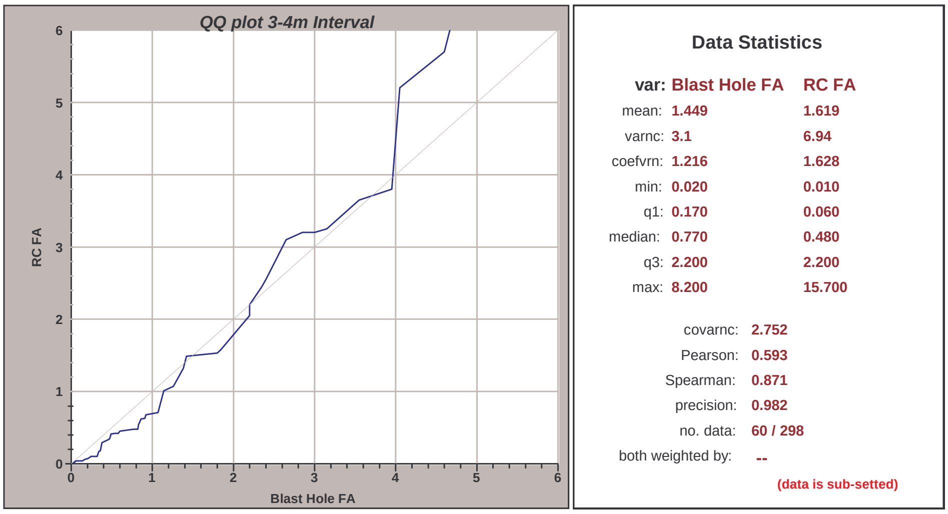

Figure 7: QQ plot RC-BH FA for 3-4 m interval

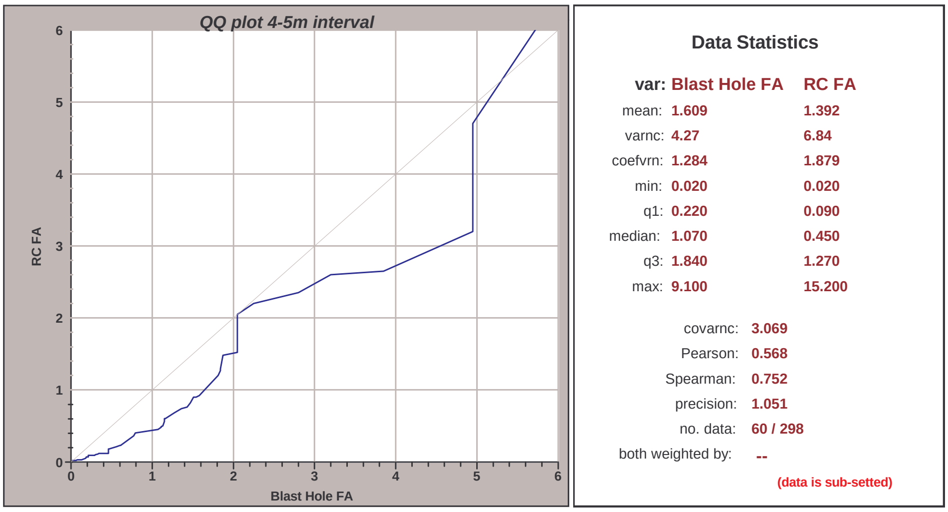

Figure 8: QQ plot RC-BH FA for 4-5 m interval

STUDY 4: COMPARISON OF RC AND BLAST HOLE SAMPLES IN A WA GOLD MINE

At an open pit gold mine in Western Australia a trial area was sampled by both blast holes and RC drill holes. Viewing plots of RC and blast hole sample grades obtained from the same drilling section indicates that down hole sample contamination is a significant problem in blast holes. Figure 9 shows the sample grades for RC and blast holes on the same cross section.

The black lines drawn on both sections are the interpreted position of the 1 g/t Au ore boundary based on the RC sample grades. Comparing the positions of these hangingwall and footwall contacts to the mineralisation envelope indicated by the blast hole sample grades shows significant differences. The hangingwall contact would be placed in a similar position, regardless of which sample grades are used, however the footwall contact would be markedly different. All blast holes that drilled through mineralisation have high grade sample grades extending below the true footwall ore contact. Four of the blast holes have interested mineralisation on this section and all of these holes have ore grade assays extending to the ends of holes. This demonstrates that down-hole smearing of gold in blast holes will lead to mining sub-economical material as ore.

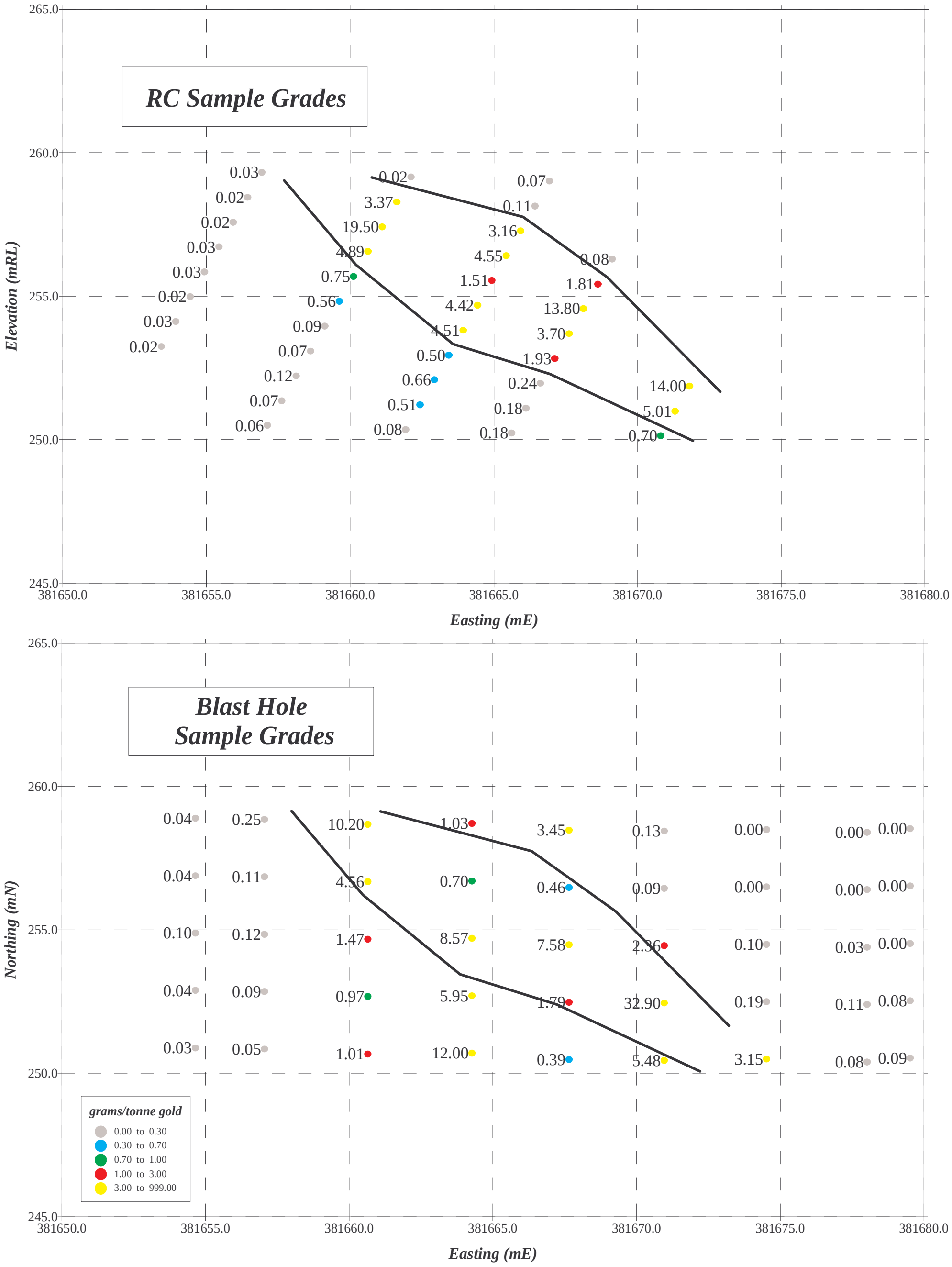

Figure 9: RC versus Blast Hole sample grades

ESTIMATING THE FINANCIAL COST OF SAMPLE BIAS

Financial losses caused by sample bias can be determined by assuming a bias typically seen in case studies and applying this to a model. If we assume that blast holes are biased 10% high for a typical 1 million tonnes per annum gold mine, we can try to determine the difference in profit for the two sampling methods.

Mill size: 1 million tonnes/yr.
Recovery : 95%
SG: 2.2 tonne/m3
Strip Ratio: 6:1
Head grade with no bias : 3g/t.
Head Grade with blast hole bias: 2.70g/t. (i.e. grade control predicts 3.0g/t. but achieves 2.70g/t. through the mill)
Mill costs: $6/tonne milled
Mining costs: $8/tonne milled
Gold price: $16.08/g.
RC cost: $15/m (on a 10 x5m pattern equates to $0.15-0.95/tonne milled depending on RC coverage)

Revenue:
Non bias case: 1,000,000T X 3.0g/t. x 0.95% x !6.08 = $45,828,000
Bias case: 1,000,000T X 2.7g/t. x 0.95% x !6.08 = $41,245,200

Costs:
Non bias case: 1,000,000T x ($6+$8+$0.95) = $14,950,000
Bias case: 1,000,000T x ($6+$8) = $14,000,000

Profit:
Non bias case : $45,828,000 - $14,950,000 = $30,878,000
Bias case: $41,245,200 - $14,000,000 = $27,245,200

Difference in profit: $3,632,800

The above numbers, while simplistic, do indicate the large potential losses incurred by using samples that are biased and that the cost/benefit of striving for representative samples is very positive.

The difference in profits would be even larger if the bias factor was increased to 20 percent (which is a realistic figure seen in the case studies above) and the RC coverage was decreased to only 50 percent of all in-pit material, which is possible in some gold deposits. Under such a scenario the difference in profit would be $8,695,600.

These scenarios make no allowance for the detrimental affect of increased random sampling errors arising out of blast hole sampling. Such errors would compound the affect of bias by increasing misclassification of ore and waste.

The figures above demonstrate that the cost of RC sampling are far outweighed by the loss in revenue incurred by incorrect grade prediction through the mill. Accurate sampling can benefit an operation by millions of dollars a year whilst the cost savings derived by using blast hole samples for grade control are an order of magnitude lower.

There are other important benefits of RC over blast hole sampling for grade control include:

- The ability to grade control well ahead of mining enables improved short-term mine, mill and financial scheduling. Such increased predictability is greatly valued by companies and shareholders.
- Modelling of mineralisation in more than two dimensions improves the definition of ore-waste boundaries and increases knowledge of ore controls.
- The ability to tailor blasting to ore boundaries greatly increases mining selectivity.
- The problem of poor sample recovery at hole collars, which also plagues RC drilling, can be overcome entirely by drilling an extra sample interval below the required bench in the current grade control pass. This sample is then used as the first sample of the next bench.
- If sample recovery from RC drill holes is systematically monitored, grade control drilling contracts can incorporate price penalties for poor sample recovery. This provides a significant incentive to contractors to play their part in maintaining the quality of the grade control process.

RECOMMENDATIONS

The following recommendations are useful for any mine interested in maximizing expected profit.

Undertake a detailed review of field sampling and drilling practices. At regular time intervals (e.g. monthly), weigh a number of drill samples to monitor sample recovery from drill holes.

Instigate and maintain a system for routine monitoring and reporting of sampling and assaying quality assurance data. This is as simple as:

- Submitting blank and standard control samples with each batch of grade control samples. Standards should preferably be made up from your own ore.
- Regularly collecting field re-split samples to monitor total sample and assay precision.
- Collating laboratory duplicate and replicate assays to monitor precision of sample preparation and analysis.
- Routinely wet screening a selection of sample pulps to monitor sample preparation efficiency.

- Routinely submit splits of sample rejects to a second laboratory for analysis, preferably by screen fire assay.

By implementing a QA programme, the mine geology department will be able to use the sample grades with the confidence of knowing their precision and accuracy. This is essential for optimising the grade control practices. Such a programme also naturally leads to increased dialogue with assay laboratory personnel and management.

Mines using blast holes for grade control sampling should conduct a trial of RC drilling over an area of representative mineralisation. The two assay populations and sets of ore outlines should be compared both spatially and in terms of predicted tonnes and grades.

A very useful comparison of two sample data sets over the same area can be undertaken using variogram modelling. Higher nuggets and shorter variogram ranges for blast hole sample data indicate the degree of random error introduced by sub-optimal sampling.

Hellman & Schofield strongly recommends that, in conjunction with any trial of RC drilling, mines undertake an orientation study to assess the impact of the MP grade control system on ore delineation and mine profit. Using conditional simulation, mines can investigate the effects of sample spacing and bench height on profit and thus derive an optimum grade control system.