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Blasthole Sampling for Grade Control – The Many Problems and Solutions

F F Pitard[1]

ABSTRACT

Conventional blasthole sampling for grade control has acquired an extremely bad reputation for the last 50 years. The introduction of many sources of bias is a structural reality. Delimitation biases are devastating. Extraction biases are of great concern as well. Weighting biases aggravate an already bad situation. Furthermore, preparation biases are many. Some of these biases are due to the type of drilling machine that is used and are nearly unsolvable. Some of these biases are due to the sampling tools that are used and often unsatisfactory. Attempts to automate blasthole sampling at the drilling site have failed, not because it cannot be done, but mainly because it interferes with drilling productivity. As a result the miner most often rejects the idea after a few weeks of practice. Manual sampling of blasthole piles is a disaster for many reasons; some are related to the methodology, some to the selected sampling protocol, some to the training of operators, some to limited manpower available, and some to limited supervision. Furthermore, with blasthole sampling a time logistic problem is unsolvable as the miner wants the ore grade control geologist to make up his mind within two or three days at most; as a result not enough time is allowed for samplers, preparation facilities, laboratory, and resources department to perform a good job as everyone is working under unreasonable pressure. The economic impact of poor blasthole sampling for grade control has been vastly underestimated by mining companies. The resulting ore grade misclassification is responsible for severe reconciliation problems and massive financial losses every year. This paper suggests areas along this grim scenario where things can be greatly improved; however it is clear that too many problems are unsolvable. An alternative using reverse circulation drilling for grade control is suggested. A thorough analysis of the respective advantages and disadvantages for blasthole and reverse circulation drilling for grade control is presented in this paper.

INTRODUCTION

Every day, at any open pit mine around the world, miners, geologists and ore grade control engineers look at assay results from samples collected from blasthole piles. This information is taken for granted as far its accuracy and precision are concerned. Data is stored on maps and become the reference few people will ever question until reconciliation problems take place between the plant, the geological block model, and the mine forecast.

Several factors play a role in these observations:

- The drilling technique was never designed to collect samples; it was designed to drill holes to fill with explosive, and that is all.
- There are no sampling tools today for collecting samples from blastholes that can be certified as correct tools. Reasons are theoretical, economical, and practical.
- The manpower devoted to blasthole sampling is at the bottom of the miner's list for the necessary competence, training, and financial resources. There is still a mentality that the data *generator* may consist of a very cheap team, while the data *interpreter* must consist of a highly educated team.
- The time allowed to collect samples from blastholes, dry them, subsample them, assay them, transfer the information on maps, perform potent geostatistics, and make the final selective decisions is totally incompatible for anyone to perform a good job. After the bench is blasted, the selective decision must be made swiftly, to satisfy a productivity philosophy strictly based on moving tons.
- Quality thinking and quality action-taking are often considered as the enemies of economic productivity (Carrasco, 2003).

But, variability at the mine, either the one belonging to the deposit, or the one artificially introduced by the way the required daily database is generated has no mercy to the interpreter and the decision maker. The financial shortcomings of this difficult chain of events are vastly underestimated because they take place in a subtle, invisible way, at least for a while.

SCOPE

The total uncertainty estimation variance σ_E^2 in a heterogeneous material drilled, sampled, subsampled and assayed can be summarised in the following formula, well known in geostatistics:

$$\sigma_E^2 = \frac{\sigma^2}{n} + \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\mathrm{cov}[x_i, x_j]$$

The first component is the variance of the random variability that does not exist in the field; it is artificially created by the selected observation module mass, sample mass, subsample mass, assaying mass, and sampling and assaying correctness. This is the component that must be minimised when sampling blastholes.

The second component is the variance in the field that must be thoroughly understood to perform effective grade control. The dependence between measurements x_i and x_j must be measured with the best precision and accuracy as possible.

If the random variability interferes too much with the estimation of the non-random variability, ore misclassification is inevitable. Furthermore, if the random variability is inflated by the variance of the sampling and analytical bias generators, ore misclassification becomes the rule, with stunning economic consequences.

The scope of this paper is to analyse the components of the random variability, how it becomes dangerously inflated with sampling bias generators, and what the mining industry should do about this silent killer.

DEFINITIONS AND NOTATIONS

The length of this paper being limited, for definitions and notations, the reader is referred to textbooks from various authors (Gy, 1979, 1983, 1992; Pitard, 1993).

LIST OF PROBLEMS WITH BLASTHOLE SAMPLING

Upward contamination during drilling

During the drilling sequence of a blasthole, upcoming chips constantly scrub the walls of the hole creating an upward contamination. The deeper the hole, the more the contamination, and there is nothing anyone can do about this problem. It is an unsolvable sampling problem.

1. Francis Pitard Sampling Consultants, LLC, 14800 Tejon Street, Broomfield CO 80023, USA. Email: fpsc@aol.com

Downward contamination

During the drilling sequence of a blasthole, the rotating rod constantly puts stress on the blasted material belonging to the former subdrill. Excessive contamination of the sample results, due to sloughing of blasted rocks. Such sloughing is not representative of the former, upper subdrill, as the contaminating material is from a depth-related cone as illustrated in Figure 1. It would be very naïve to believe such contamination compensates for the fact that almost zero recovery is achieved during the drilling phase of the former subdrill.

Upward losses during drilling

Rock chips on their way up during the drilling phase can find their way into cracks, fissures, fractures, and already broken up material, as they reach the former subdrill, as illustrated in Figure 2.

Refluxing during drilling

The deeper the drilling, the more the refluxing of coarse material is taking place, as illustrated in Figure 2. This is easily observed in the blasthole pile after the drilling machine moves away; the

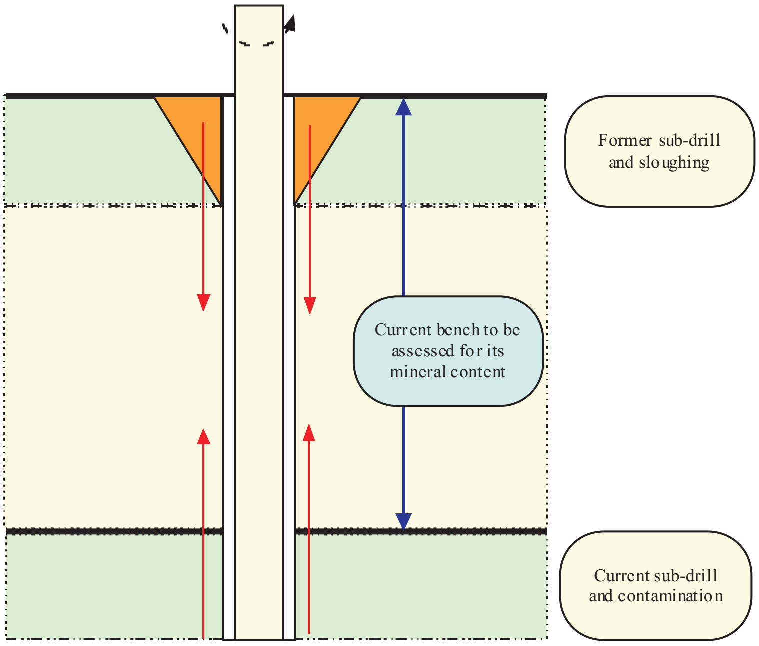

FIG 1 - Cross-sectional view of blasthole drilling illustrating sloughing and subdrill zones.

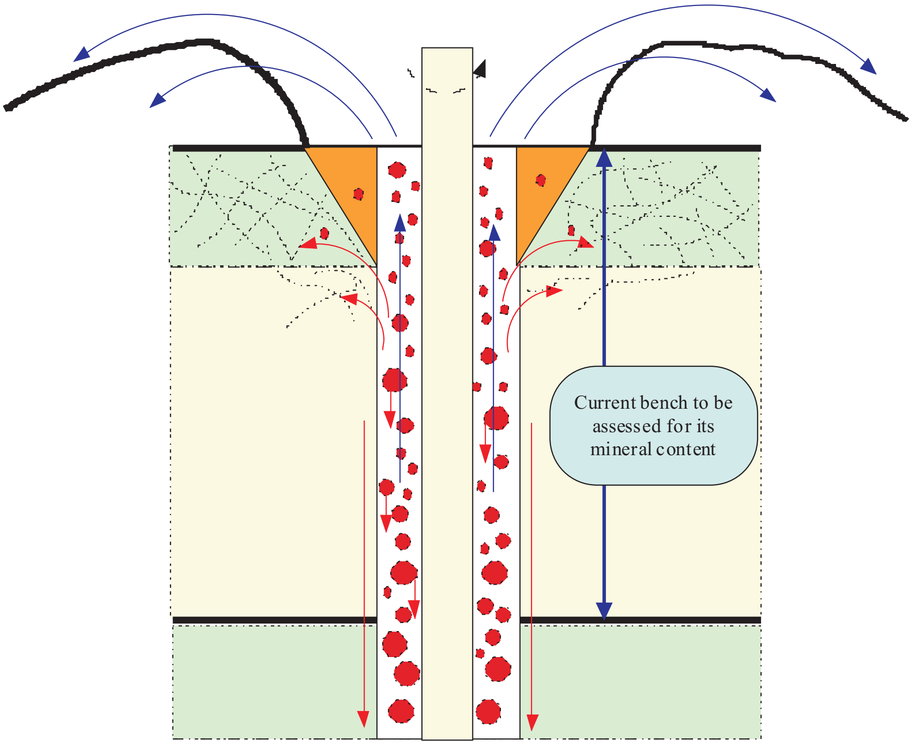

FIG 2 - Coarse fragments refluxing, and fragment losses into fractures.

material at the bottom of the pile is usually much coarser than the material at the top of the pile. It is not clear what happens to the refluxing material. It may regrind and finally find its way up, but this process is another open door for bias-generating sample recovery problems.

The necessity of the subdrill

The subdrill, as illustrated in Figure 3, A and C, is a logistic necessity for the miner, to blast below the actual bench in order to prepare a smooth access to the mining equipment, such as shovels, trucks, and driving personnel. Most of the material blasted within the subdrill remains where it is, *in situ*, though some of it moves aside with dozers and graders, and some of it indeed finds its way to the plant or the waste.

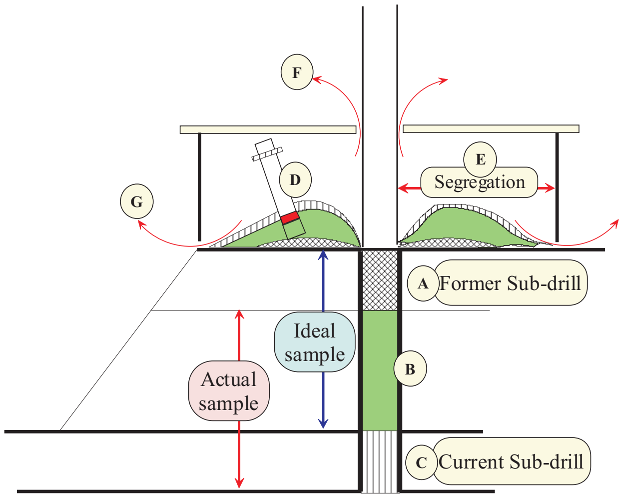

FIG 3 - Summary of blasthole sampling problems.

Subdrill material at the top of the pile

The biggest problem with the subdrill material is that it comes at the worse possible place, at the top of the blasthole pile where it is easy for the operator to take the material into a sample. The author visited many mines where the subdrill was included in the sample, and it should not be. An illustration of this problem is shown in Figure 3, areas C and D. The author even saw some cases where the sample going to sample preparation facility was made only of the subdrill, especially when operators are not aware they are observed from a long distance.

Recovery of the former subdrill

The former subdrill area is already broken up when drilling a new bench. During that phase it is easy to observe the recovery of chips into the blasthole pile is practically nil, as illustrated in Figure 3, area A. Experience proves that such unacceptable recovery may actually last for three or even four metres.

Recommended test

Let's assume a 10 m bench is drilled, with an additional 2 m subdrill. Before drilling starts, place a correctly designed radial bucket near a new hole. Drill for 5 m, retrieve the sample, and weigh it. Then drill for an additional 5 m, retrieve the sample, and weigh it. It can be shown that the weight of the first sample is rarely more than 60 to 70 per cent of the weight of the second sample.

This is a huge, unsolvable extraction bias, demonstrating that even if someone could collect the entire pile, it would still be impossible to obtain a representative sample. It is fair to say that blasthole samples vastly over-represent the second half of a bench. If subhorizontal geological structures exist, massive ore grade misclassification may take place, and there is nothing the grade control engineer can do about it.

Some people do not want to include any foreign material accumulated at the top of a new mining bench into the blasthole samples because such material is not representative of what was predicted by the geological model. The argument and way of thinking is fully understood; however, the only purpose of blasthole samples is to predict the average grade that goes to the mill, regardless of its real origin; therefore, the material in the former subdrill must be accounted for by the sample, and there is nothing to debate about this fact.

Pile segregated laterally

Due to many factors such as size, density, and shape of fragments, wind, rotation speed of the drilling rod, and compressed air, enormous lateral segregation can be observed in the blasthole pile. Such segregation is an evil, transient phenomenon changing all the time. As a result it would be unwise to collect all increments at a same distance from the centre of drilling, as many people do. A good way to account for such segregation is by using a radial bucket correctly designed and correctly positioned at random around the hole, as illustrated in Figure 4; its edges must be radial toward the centre of drilling. The problem with the radial bucket arises when the bench is thick (eg 15 m) and the hole is of a large diameter. In such a case up to two or even three tons of material lies on the ground. Since the small opening of the radial bucket should be at the very least three times the size of the coarsest fragments, the radial sample may weigh several hundred kilograms which is not practical on a routine day. Drilling holes with an electric auger may solve the problem as long as the holes pattern try to simulate a radial cut as illustrated in Figure 5B. A pattern looking like a cross, as shown in Figure 5A, would be fundamentally wrong and would introduce a delimitation bias. For very large piles created by large drilling diameter and very thick mining benches, an option that gives reasonable results is the one illustrated in Figure 6. Overall, it is very difficult if not impossible to account for lateral segregation; a bias is likely to take place. Furthermore, current sampling practices observed in a large majority of open pits are a total disgrace as far as this issue is concerned.

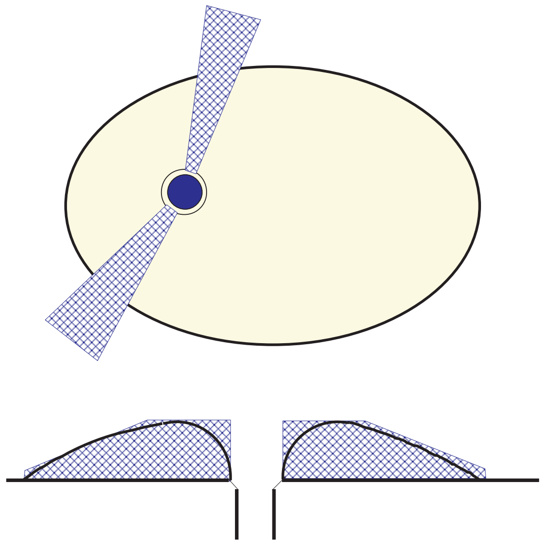

FIG 4 - Correct design and positioning of a radial bucket.

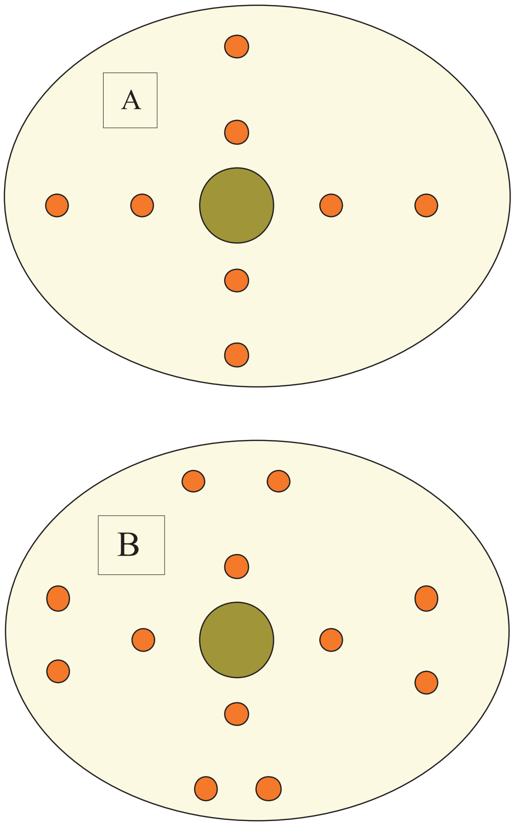

FIG 5 - (A) Holes pattern introducing an intolerable delimitation bias; (B) a better holes pattern simulating a correct radial cut.

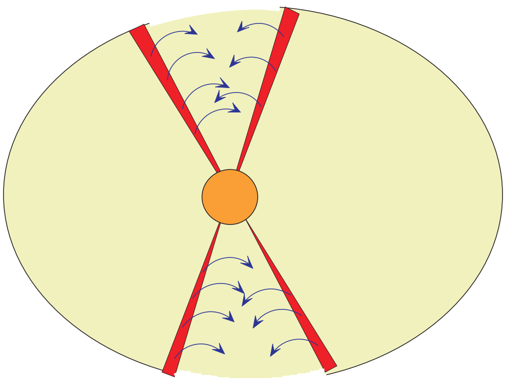

FIG 6 - Digging two large radial channels, and collecting four thin, radial increments to make a composite sample.

Pile segregated vertically

The blasthole pile is vertically segregated with layers as illustrated in Figure 3. Many mines sample blasthole using a tube. There are several problems with this tool: the tube can rarely reach the bottom of the pile; the sample recovery is a function of depth, good at the beginning, poor about half way down, and nil about two-thirds of the way down. This sequence is illustrated in Figure 3D, and confirmed by the energy required from the operator to reach the bottom of the pile. In summary, sampling blasthole with a tube introduces a massive delimitation bias, always combined with a massive extraction bias; it is the worst nightmare scenario for grade control. Reproducibility around the pile is misleading as all samples would be biased more or less the same way, and there are no practical solutions. There is a better chance using an electric auger, the diameter of which must be about eight times the size of the coarsest fragments to be sampled. If the diameter of the auger is smaller, an extraction bias will favour fines over coarse fragments. Either way, tube or auger, it is impossible to accurately decide about the thickness of the material at the top of the pile, representing the subdrill. Clearly, both approaches are unsatisfactory.

Pile shape irregularity

Blasthole pile shape irregularities can be induced in several ways. The dominant wind can play a role, and the place where curtains are installed may provide a too narrow area for the pile to keep its integrity. This problem, as bad as it may seem, is actually not a dominant one, as no matter what, the pile is highly segregated anyway. However, it would be a mistake to believe that such induced irregularity may randomise the place of fragments in the pile and somewhat homogenise the pile. In reality, the segregation just gets worse.

Curtains and losses of fines

The attitude of drilling operators refusing to use available curtains to prevent the excessive dispersion of fine particles far beyond what is reasonably reachable when collecting samples, is costing mining companies a fortune in good ore lost to the waste, as in most cases fines are richer than the coarse fragments. Maintenance of these curtains is also responsible for excessive loss of fines. As the drilling progresses, curtains must be in contact with the ground all around the machine. This should not be considered as a trivial mistake; it is a cardinal one, bordering on fraud and sabotage. It is of the utmost importance for top management to investigate this problem in the strongest possible terms otherwise most of subsequent efforts to perform grade control become a loss of time and money.

Deterministic and operator-dependent sampling

The idea is: 'Catch whatever you can, as long as it does not cost money.' There is no other management misconception that will generate as severe, invisible costs. In this case, the operator is collecting some material from the part of the pile that is easily accessible with scoops, shovels, tubes, … aware of segregation problems, perhaps, the operator tries to collect as many increments as practically possible. Nevertheless, a large fraction of the pile is systematically kept away from the sampling tool. There is no way to assess the money losses generated by such non-probabilistic, convenient approach. It is fair to say that management places its destiny in the hands of low-paid, poorly-trained operators. It is not good, but this proved to be a real world scenario commonly observed.

Sampling interfering with mining productivity

The historical practice is that the miner is on a mission to blast and move as many tons as possible during a working shift, and anything in his way must be cursed. This is one of the main reason blasthole drillers, under tight miner's supervision, are not given the task of collecting samples.

Automation of sampling is a miner's enemy

Many attempts have been made around the world to automate sampling of blastholes by installing a sampling station either directly on the drilling machine or nearby on a separate truck. Such systems have been working well (Pitard, 2004), but in all cases they clearly slow down the blasthole drilling productivity, which is considered a cardinal sin by mining management. As a result ways are quickly found to dismiss the unwelcome, intruding system.

Sample mass requirements

Mining engineers have also resisted the necessity to increase blasthole sample mass. In many mines around the world it is common practice to collect 5 - 7 kg samples. Nobody can collect a representative 5 - 7 kg blasthole sample. Most mines require 15 - 20 kg samples in order to perform an average quality sampling job. Many gold mines should collect 20, 50 kg samples or even more. There again, excessive manpower in the pit, and necessary large sample preparation facilities make such protocols a cardinal sin for the accounting controller who has an obsession with visible costs alone. Let's make no mistake, too small blasthole samples vastly inflate precision ellipses drawn around the points of a scatter plot on which results from duplicate blasthole samples have been plotted. Such ellipse can roughly quantify the magnitude of the amount of ore and waste misclassified around a pre-selected cut-off grade, leading to the real cost of precision, and most of the time the conclusion is very ugly, although not accurate and precise enough to be used in accounting books.

Turnaround time

Sample collection time

An efficient team is capable to collect all blasthole samples for one working shift within four hours. It is not cost effective for one or two operators to wait for each hole to be completed. This task should be done all at once after many holes have been drilled.

Necessary drying time

The necessary drying time for blasthole samples is a minimum of eight hours at a temperature of 107°C ± 5°C. Little moisture remaining in the samples would drastically reduce the efficiency of a jaw crusher during the preparation stage.

Necessary sample preparation time

The blasthole samples generated by one working shift require about eight hours of sample preparation work for a well-trained team aware of all the important details that must be considered to prevent contamination, losses, and alteration of physical or chemical components important to grade control.

Necessary assaying time

The blasthole samples generated by one working shift require about eight hours of analytical work for a well-trained team aware of all the important details that must be considered to prevent contamination, losses, calibration biases, weighing baseline biases, incomplete sample dissolution biases, and interferences.

Necessary geological and geostatistical interpretation time

The geologist and geostatistician need an additional eight hours to transfer all the laboratory information into production maps and make appropriate calculations about ore boundaries, and deliver this information to the mining engineer.

The conclusion is that blasthole samples cannot provide relevant quality information to the mining engineer in less than 36 hours. More often than not, the mining engineer cannot afford to wait that long to make up his mind about in-pit ore/waste selectivity. As a result, everyone, the sampling team, preparation team, laboratory team, geologist and geostatistician are working under enormous pressure and therefore nobody can perform a reliable job. The resulting cost from ore grade misclassification is enormous but always goes undetected for long periods of time until someone attempts to make reconciliations: usually, a scapegoat must be killed.

Vertical blastholes

Blasthole drilling is necessarily vertical for logistic blasting necessity. But, often, mineralisation is either subvertical or horizontal. In the first case, illusions of high-grade and low-grade zones are created that are completely incompatible with the size of the mining equipment. In the second case, massive misclassification is likely to take place as the second half of the bench represents at least 60 to 70 per cent of the blasthole pile. It is important to note that this problem is unsolvable, nevertheless devastating.

Massive misclassification of ore and waste

The ore/waste misclassification generated by blasthole sampling is far more severe than what the mining engineer is willing to recognise. As a result, reconciliation between blasthole predictions and what the mill may eventually get is an unrealistic dream. The idiosyncrasy of blasthole sampling is so complex that economics justifying blasthole sampling versus reverse circulation drilling for grade control are always biased in a naïve way toward blasthole sampling. Such economics, most of time, miss at least 90 per cent of the relevant points.

Absence of valuable information from the bench below the actual mining bench

Good geostatistics require information from above and below the actual mining bench if reliable kriging techniques are to be used. Blasthole sampling cannot provide such critically important information, therefore any subsequent averaging or kriging technique is necessarily weak.

The few advantages of blasthole sampling

Blasthole sampling has a few advantages however they are undoubtedly outweighed by the many devastating disadvantages. In some cases, these advantages are highly questionable.

One drilling technique for blasting and for grade control

The use of only one drilling technique for blasting and for grade control gives the illusion to the accounting controller that money is saved that way. It also gives the illusion to the mining engineer that better mining efficiency is reached. The advantage of such illusions is the delivery of peace of mind to many people. Nevertheless, nobody would dare say blasthole drilling cannot and will not provide representative samples.

Small visible cost

Sampling blastholes can be performed by low-paid people, and this is the only relevant cost for the accounting department in charge of tracking costs to the last decimal point and finding ways to cut them. Blasthole correctness becomes operator-dependent and non-probabilistic. The magnitude of the cost of such determinism is inaccessible to accounting controllers and to mining engineers as well.

Good lateral interpolation

The fact that blastholes are at very short distance from one another (eg 7 m) gives the impression that excellent lateral knowledge is acquired and should provide superior information for grade control. This also is a naïve illusion. The reason is that all samples are heavily biased toward the second half of the bench, therefore the lateral advantage they are supposed to deliver has been mostly lost. Correct samples at 15 m intervals can provide much better information than heavily biased samples at 7 m intervals.

Less traffic in the open pit

The clear advantage of blasthole sampling is to minimise traffic in the pit during mining production. On this issue, the mining engineer rules the game and it is fair that way.

ADVANTAGES OF REVERSE CIRCULATION DRILLING FOR GRADE CONTROL

A separate drilling campaign using quick reverse circulation drilling is the solution, and the advantages are many.

Absence of a subdrill

The absence of a subdrill allows correct sample delimitation followed by correct sample recovery. The elimination of these devastating sampling biases invalidating blasthole sampling is an economic advantage that would deserve more in-depth study as it may be in the order of five to 15 per cent of total revenues for many mining operations.

Possibility to drill several benches at once

Grade control on multiple benches can be completed at the same time. This allows the use of more professional geology and geostatistics, resulting in better short-term and mid-term mine planning.

Possibility to drill at an appropriate angle

The possibility of drilling at the right angle so subvertical veins are no longer missed most of the time should be a cardinal rule in grade control. Reverse circulation drilling provides such essential flexibility, leading to more realistic bench evaluation.

Limited contamination and losses

Drilling chips are fully protected inside the drilling rods all the way to the cyclone, minimising upward contamination, refluxing, and upward losses. Losses from exposure to wind are also nonexistent.

Possibility of drilling on inactive benches, away from blasthole drilling

Since reverse circulation drilling can be planned many months ahead of time, it is up to the mining engineer to plan such drilling on inactive benches, away from current blasthole drilling. Poor planning would obviously turn this advantage to a potentially serious problem.

No interference with mining productivity

The increase of traffic in the pit can also be minimised if good advanced planning is performed. Reverse circulation drilling should not interfere with mining productivity unless last-minute planning modifications are the rule.

Possibility of drilling many months ahead of mining time

The possibility of drilling for grade control many months in advance presents many valuable advantages for the geologist, grade control engineers, sample preparation facilities, laboratory, and geostatisticians. As all these pressure-limiting problems are eliminated, more valuable metals going to the right place are soon accounted for.

Possibility of drilling less, better holes

Less reverse circulation holes are necessary as all samples are representative of a well-known sampling interval, which is not the case for blasthole samples regardless of how close they are to one another.

Smaller sample mass

Reverse circulation chips are slightly smaller than blasthole drilling chips, making it possible to collect a smaller sample mass and still provide sufficient precision to minimise the devastating effect of precision around the selected cut-off grade.

More information from lower benches

The additional information from lower benches generated by reverse circulation drilling allows the geologist and geostatistician to better model the actual resources in the current bench to be mined. This in turn may minimise ore grade misclassification and provide more short-term revenues. Such advantage, sustained every day for years, can truly change the recovery economics of a deposit.

Better vertical definition of ore and waste

Reverse circulation drilling combined with an automated on-rig sampling station can provide representative samples every 3 - 5 m, providing an unsurpassed definition of ore boundaries. Such advantage acquired long in advance can actually impact short-term and long-term planning of the mining operation, leading again to better and far more reliable metal recovery economics.

Turnaround time

Plenty of time to dry, prepare, and assay samples, completely liberates sample preparation facilities and laboratories from negative productivity stress, allowing the creation of a far more reliable database. Furthermore, the geologist and geostatistician benefit from ample time to make a thorough interpretation of the grade control data.

Better mining logistics

The only purpose of reverse circulation drilling is grade control. Better short-term and long-term planning also impacts the way large machinery logistics is dealt with in the pit, allowing better planned preventive maintenance and better distribution of work with contractors. Reverse circulation drilling can be campaigned, which allows drilling to be performed during preferred seasons, unlike with blasthole drilling that must be done continuously regardless of weather conditions.

Automation of sampling is easy

The automation of sampling on the reverse circulation drilling rig is already well established, therefore there is no doubt quality work can be achieved in a predictable manner.

More accurate and precise grade control

Conditional biases can be eliminated with reverse circulation drilling, which is not the case with blasthole drilling. The precision of the sampling protocol can also be better controlled as much more time is allowed to QA/QC protocols.

Drilling machines can be used for local exploration

Reverse circulation drilling machines can be campaigned for near-pit additional exploration for new natural resources.

The few disadvantages of reverse circulation drilling for grade control

There is an additional, visible drilling cost. There is increased traffic within the pit. If the pit design is such that benches are accessible only one way, the excess traffic may become unacceptable.

CONCLUSIONS AND RECOMMENDATIONS

Blasthole sampling cannot provide representative samples, as many listed problems are unsolvable ones. The economic impact of such shortcomings is vastly underestimated by the mining industry.

The reverse circulation drilling alternative presents many advantages that may far outweigh its additional, visible cost.

It is highly recommended that mining companies take a fresh look at the economics of reverse circulation drilling for grade control, rather than cherishing the old ways that lead to massive reconciliation problems later on.

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