Sampling mineral commodities—the good, the bad, and the ugly

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Synopsis

A wide range of drill holes and process streams are sampled for resource estimation, grade control, and contractual purposes in the minerals industry. However, despite the availability of training courses, conferences and both national and international standards on correct sampling practices, it is still surprising how often little attention is given to ensuring that representative samples are collected for analysis. The reason for this is that the responsibility for sampling is often entrusted to personnel who do not appreciate the significance and importance of sampling, with cost being the main driving force rather than whether the sample is representative of the material from which it was extracted. This seriously undermines the precision and accuracy of the analyses subsequently generated and can render the analysis process a total waste of time and money and expose mining companies to serious, potential, financial losses. Company management needs to reverse this situation and ensure that sampling is given the attention it deserves to generate representative samples for analysis.

Introduction

Samples are taken from a broad range of locations in the mining industry for grade control, including blast holes, feed and product streams, conveyor belts, trucks, railway wagons, and stockpiles. This process is vital to mining companies for metallurgical accounting, optimizing resource utilization, and maximizing profitability (Holmes[1]), yet the number of instances where poor sampling practices are used is unbelievably large even in this technologically advanced day and age. The main reason for this is that sampling is often left to personnel who do not understand its critical importance in generating representative samples and subsequent analyses that are truly meaningful and can be relied upon to make correct grade control decisions. It is not good enough just to collect some material and send it back to the laboratory for analysis if the sample is not representative in the first place. The whole exercise is simply a waste of time and can lead to suboptimal recovery in processing plans, reduced mine life, and loss of sales revenue. It is, therefore, critical to ensure that samples be free of significant bias and that the overall precision of the final analysis is appropriate for the required grade control task

The 'golden rule' for correct sampling is that 'all parts of the material being sampled must have an equal probability of being collected and becoming part of the final sample for analysis'. If this requirement is taken into account at the outset in designing a sampling system, then good progress towards obtaining representative samples is assured. On the other hand, if this rule is not respected, then sample bias is easily introduced. Key design flaws that need to be eliminated (Gy[2]) include incorrect delimitation of increments, i.e., incorrect cutter/increment geometry, incomplete extraction of increments, preferential exclusion of specific size fractions, sample loss, and sample contamination. In this regard, it is not easy to take correct samples from some of the sampling locations listed above and should be avoided, e.g., it is impossible to take a representative sample *in situ* from a large stockpile.

Components of sampling error

It is instructive to list the key components of sampling error (Gy[2], Pitard[3]) to better understand how to eliminate or minimize them. The key components are as follows:

- Fundamental, grouping, and segregation errors
- Long-range quality fluctuation error
- Periodic quality fluctuation error
- Weighting error
- Increment delimitation error
- Increment extraction error
- Accessory errors.

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Of these errors, the weighting, increment delimitation, increment extraction, and accessory errors lead to bias and need to be eliminated, while the others including the fundamental, grouping and segregation, long-range quality fluctuation, and periodic quality fluctuation errors need to be reduced to achieve acceptable precision. Minimizing or even better eliminating bias is critical, because bias cannot be eliminated once it is present. There is no point in being 'precisely incorrect'. Sources of bias that can be eliminated include incorrect delimitation and extraction of increments, sample spillage and sample contamination, while sources of bias that need to be minimized include changes in moisture content and dust losses.

Elimination of increment delimitation and extraction errors is particularly important, because, together, they are responsible for a large proportion of incorrectly designed sampling systems. These two errors arise from incorrect, increment delineation due to bad sample cutter design and subsequent extraction of the increment that is collected. The delimitation error is eliminated if the cutter geometry is correct, e.g., selection of a parallel section of ore on a conveyor belt or radial cutter lips on a rotating Vezin cutter (see Figure 1), whereas the extraction error is eliminated if increments are completely extracted without any sample loss (e.g., no reflux or loss of sample from the cutter aperture).

Accessory errors are also common in badly designed and maintained sampling systems and where operator training is poor and procedures are not regularly checked. Such errors include sample contamination, loss of sample such as dust (see Figure 2), alteration of the chemical composition of samples, loss of moisture (see Figure 3), particle degradation, operator mistakes, such as mixing up sample labels, fraud and sabotage. An example of fraud is collecting a 'timed' sample well in advance of the time at which it is scheduled to be taken.

Blast hole sampling

Blast hole sampling is quite problematic for a range of reasons, including segregation of the drill cuttings (see Figure 4), non-uniform thickness of cuttings in the cone and correctly allowing for sub drill cuttings generated by drilling

Figure 1—Correctly designed rotating Vezin cutter with radial cutter lips

(a)

(b)

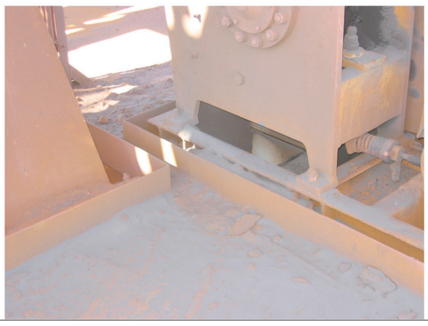

Figure 2—Examples of unacceptable sample loss due to (a) a hole in the side of a chute and (b) windage underneath a jaw crusher

Figure 3—Moisture loss from an open slow moving conveyor transferring primary increments from the primary cutter to the secondary cutter

Figure 4—Cone of blast hole cuttings showing the large variability in the cuttings and hence the difficulty in extracting representative samples

below the design depth of the bench. In addition, because the top of the bench is fractured due to prior blasting, relatively few cuttings are generated from the top few metres of the blast hole, so the cone of cuttings is biased towards the material in the middle and lower sections of the bench. Separate reverse circulation (RC) drilling for grade control purposes is currently considered to be the best solution (Pitard[4]), although this adds considerably to the overall costs. The drill cuttings are easier to collect using this approach due to the smaller sample masses involved and multiple benches can be drilled at the same time.

Confining the discussion to sampling of blast hole cones, a number of methods are used as follows:

- Taking vertical slices from one of more slots dug into the side of the cone of cuttings
- Taking two complete channel cuts through the whole cone (see Figure 5(a))
- Extracting one or a number of complete radial sectors from the cone of cuttings using 'sector cutters' (see Figure 5(b))
- Automatic collection and division of the cuttings on the drill rig using compressed air/suction and a cyclone to separate out the cuttings.

Of the above options, whereas the last method is in principle the best approach, a substantial proportion of the cuttings is not picked up by the sample collection system (usually the coarser particles) and the cyclone and sample division system tends to clog up when wet cuttings are encountered. In addition, the first method is very subjective about where the vertical cuts are taken, leaving channel sampling and use of sector cutters as the best approach for sampling the cuttings from blast holes.

(a)

(b)

Figure 5—Sampling of blast hole cuttings by (a) manual extraction of two channel cuts 180° apart and (b) using a sector cutter during drilling

Plant sampling

Sampling particulate material

The best location for sampling a process stream in a mineral processing plant is at the discharge point of a conveyor belt or chute where the complete stream can be intersected at regular intervals. The design rules for such a sampling system are as follows:

- The sample cutter must take a complete cross-section of the process stream
- The cutting time at each point in the stream must be equal
- The cutter should intersect the stream in a plane normal to the stream trajectory
- The plane of the cutter aperture must not be vertical or near vertical, because particles that strike the inside edge of the cutter lips (and hence which should appear in the sample) are deflected away from the cutter aperture into the reject chute
- The cutter speed must be uniform duting its traverse through the stream
- The cutter aperture must be at least three times the nominal top size (d) of the particles being sampled, i.e., 3d
- The cutter speed must not exceed 0.6 m/s unless the cutter aperture exceeds 3d
- There must be no contamination of the sample or change in its quality
- Bucket-type cutters must have sufficient capacity to accommodate the entire increment without any overflow or loss of sample
- The sample cutter must be non-restrictive, self-clearing and discharge completely each increment, and for high capacity streams have a large cutter body and streamline design to eliminate sample reflux
- Belt scrapers need to be located so that the scrapings are intersected by the sample cutter.

A well designed cross-stream sample cutter with a large body to accommodate high capacity streams is shown in Figure 6(a). The back of the cutter is designed to direct incoming material downwards towards the exit chute at the bottom of the cutter, thereby minimizing build-up of material in the cutter throat during sampling and hence sample reflux. On the other hand, the cutter shown in Figure 6(b) has inadequate capacity for high capacity streams and sample reflux from the cutter aperture is evident.

Other examples of poorly designed sample cutters are shown in Figure 7. The primary cutter in Figure 7(a) has vertical cutter lips and very limited capacity to accommodate the sample being collected; the cutter in Figure 7(b) is a bucket-type secondary cutter with a number of problems. In the latter case, the gap between the dump gate at the bottom of the cutter and the cutter body is excessive, resulting in sample loss from the cutter during its traverse. In addition, there is substantial build-up on top of the cutter that can potentially contaminate the sample when it is dumped at the end of the cutter traverse.

The cutters, discussed so far, have been cross-stream cutters where the cutter passes through a falling stream of material, and, hence, it is reasonably straightforward to

(a)

(b)

Figure 6—Examples of cross-stream primary cutters that are (a) well designed for sampling high capacity streams and (b) of insufficient capacity resulting in sample reflux from the cutter aperture

(a)

(b)

Figure 7—Examples of poorly designed and maintained primary and secondary cross-stream cutters. The primary cutter in (a) has vertical cutter lips and very limited capacity; there is sample loss from the gate at the bottom of the secondary cutter in (b) as well as build-up on top of the cutter

ensure that the cutter intercepts the complete stream. In addition, it is reasonably easy to check visually that cross-stream cutters are operating correctly, (i.e., that increment delimitation and extraction are correct), thereby reducing the need for expensive bias tests. In contrast, cross-belt cutters take samples directly off conveyor belts, but it is very difficult to check visually that they are operating correctly and remove a complete and correctly delimited cross-section of material from the conveyor belt. Often such cutters leave a layer of material on the conveyor belt due to wear/incorrect adjustment of the skirts on the bottom of the cutter or the deliberate action of maintenance staff who leave a gap between the bottom of the cutter and the conveyor to eliminate possible damage to the conveyor belt. Consequently, expensive bias tests are required to assess their performance. For the above reasons, cross-stream cutters are recommended in preference to cross-belt cutters, particularly for high capacity streams.

Examples of cross-belt cutters are shown in Figures 8 and 9. In the cross-belt cutter installation, shown in Figure 8, the cutter is fully enclosed, so it is impossible to check its operation. Figure 9 shows two poorly designed cross-belt cutters. In Figure 9(a), the conveyor belt profile does not match the trajectory of the cutter, so there are gaps where material on the conveyor is not collected. The design of the cross-belt cutter shown in Figure 9(b) is much worse and is no more than a ‘paddle’ that removes some material from the conveyor belt. Analysing samples collected by a device such as this is really a complete waste of time because there is no way that the samples will be representative.

Manual sampling from the top of conveyor belts (see Figure 10) is also totally unacceptable for a number of reasons. Firstly, there are serious safety issues with this practice and, secondly, it is not possible to take a complete cross-section of the material on the conveyor belt. Consequently, the sample collected will not be representative.

Sampling dry concentrates

The requirements for sampling dry concentrates are essentially the same as those for sampling particulate material, except that the particle size is much smaller. Hence, a cutter that takes a complete cross-section of the concentrate

Figure 8—Fully enclosed cross-belt sampler installation

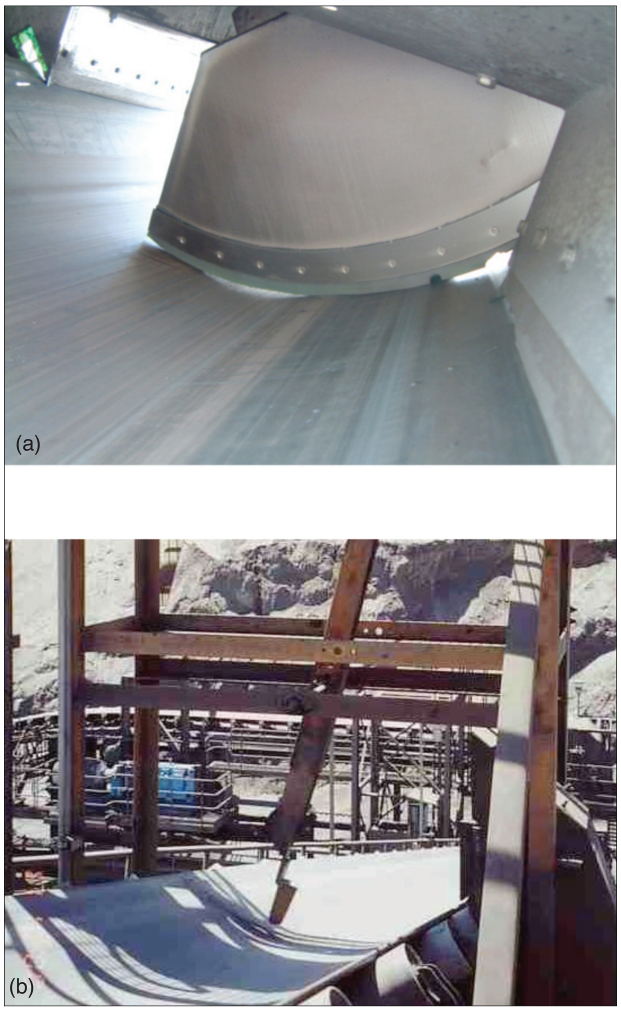

Figure 9—Examples of poorly designed cross-belt cutters. In (a), the conveyor profile does not match the cutter trajectory; in (b) the cutter is simply a paddle

Figure 10—Manual sampling from the top of a conveyor belt raises serious safety concerns and in any event does not provide a representative sample

stream at a transfer point is required, the recommended minimum cutter aperture being 10 mm. However, *in situ* 'dip' sampling from holding tanks and vessels is carried out as shown in Figure 11, but this is not recommended because the concentrate will almost certainly segregate in the vessel, resulting in a non representative sample.

The only acceptable way of extracting representative samples *in situ* from vessels is full depth sampling where a number of full vertical columns are extracted from the vessel or sampling from a moving stream as the vessel is filled or emptied. In the latter case, dry concentrates are occasionally sampled while they are being conveyed via feeder tubes into vessels, but, once again, this is satisfactory only if the cutter extracts a full cross-section of the concentrate stream. Using a pneumatic sampling device attached to the side of the feeder tube (as shown in Figure 12) is not satisfactory, because the full cross-section of the stream is not sampled

Figure 11—Manual sampling of vessels using a ladle is not recommended due to segregation of the material in the vessel

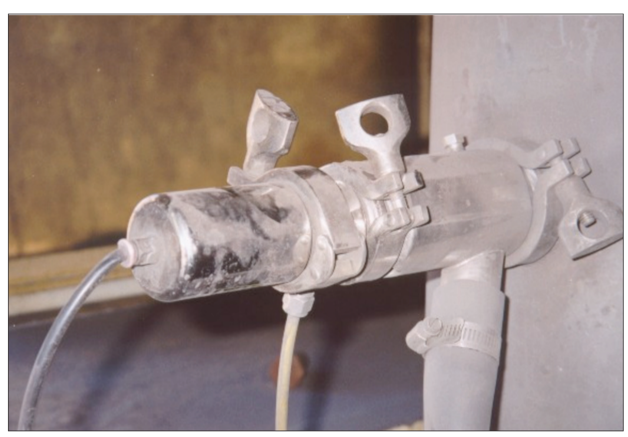

Figure 12—Sampling dry concentrates pneumatically from the side of a feeder tube does not extract a full cross-section of the concentrate stream and generates a biased sample

Figure 13—Examples of (a) a full cross-stream slurry sampler and (b) manual sampling of a slurry stream using a ladle that is too small for the stream being sampled

and the suction action of the sampler will preferentially collect the smaller, less dense, particles, resulting in a seriously biased sample.

Sampling slurries

As for sampling particulate materials and dry concentrates, the best location for sampling a slurry is at a transfer point where a cross-stream cutter can gain access to the full slurry stream and take a complete cross-section of the stream (see Figure 13(a)), thereby providing a representative sample. Taking samples using a ladle that does not intercept the full slurry stream as shown in Figure 13(b) is not acceptable. One key difference with slurries is the need to ensure that 'dribbles' from underneath pipes and launders are also intercepted by the sample cutter, as illustrated in Figure 14.

Although it is common practice in industry, sampling of slurries via 'taps' on the side of pipes is not satisfactory for extracting representative samples because segregation and laminar flow of slurries in pipes are common. Examples of this unsatisfacory practice are shown in Figure 15. In addition, pressure pipe samplers used for extracting samples for on-line analysers (see Figure 16) do not extract a full cross-section of the slurry stream, so they are prone to bias as well.

Sampling trucks, railway wagons, and stockpiles

Sampling of material that is stationary (e.g., in trucks, railway wagons and stockpiles) is particularly problematic because in many cases it is not possible to ensure that all parts of the material being sampled have an equal probability of being collected and becoming part of the final sample for analysis, particularly for large stockpiles. Other than sampling the material from a moving stream, when the material is transferred to or from the truck, railway wagon or

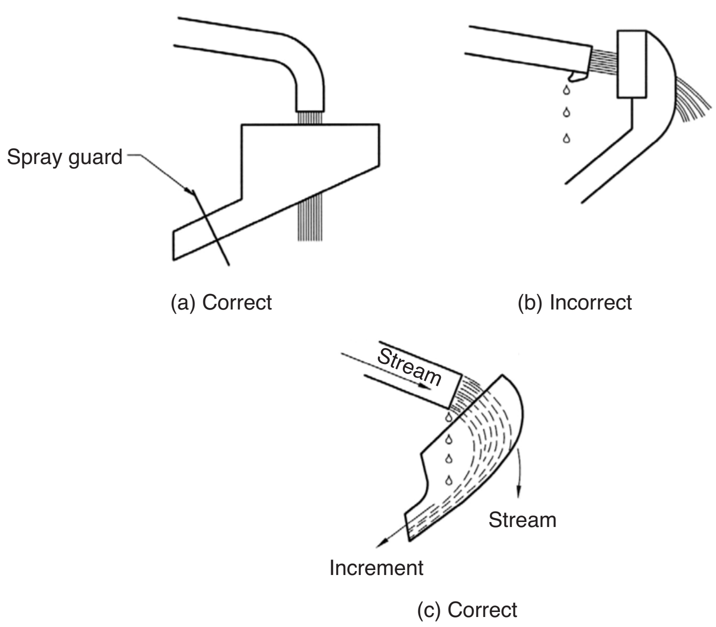

Figure 14—Examples of correct and incorrect cutter designs for sampling slurries

Figure 15—Taps from the side of slurry pipes do not extract a full cross-section of the slurry stream, so the samples will not be representative

Figure 16—Pressure pipe samplers do not extract a full cross-section of the slurry stream, so the samples taken are unreliable

stockpile, the only way of obtaining representative samples is to drive an auger or spear down to the bottom of the truck, railway wagon or stockpile and then extract the full vertical column of material without any sample loss. Collecting material from the tops of railway wagons or from the side of a stockpile (as shown in Figure 17) will not provide representative samples.

Sample preparation

The preparation of mine and/or plant samples in the sample preparation laboratory prior to chemical analysis is as important as the primary and subsequent sampling steps in ensuring that the final sample submitted for analysis is representative. In fact, there are many instances where the veracity of the sample delivered to the sample preparation laboratory is totally destroyed in the preparation process by dividing the sample down to a sample mass that is too small for the nominal top size of the material being prepared, (i.e., the minimum sample mass requirements are not observed, (Gy[2] and Pitard[3])). This is illustrated in Figure 18, where the sample mass has been divided down to about 300 g for pulverization, but the sample is far too coarse(~10 mm) for division down to this sample mass, resulting in poor division precision. The sample should have been crushed to a much smaller particle size (~3 mm) prior to division.

Other sample preparation problems that need to be eliminated include:

- ➤ Discarding part of the sample because it is too heavy
- ➤ Incorrect use of sample dividers, e.g., riffles
- ➤ Sample loss in dust extraction systems
- ➤ Cross contamination between samples.

Robotic sample preparation systems are increasingly being used to overcome occupational health and safety restrictions on sample masses and the vagaries of manual sample preparation, but they still need to be carefully

Figure 17—Sampling from (a) the top of railway wagons and (b) the side of stockpiles will not provide representative samples

Figure 18—Example of a sample ready for pulverization prior to analysis, but the sample mass is far too small for the nominal top size of the material

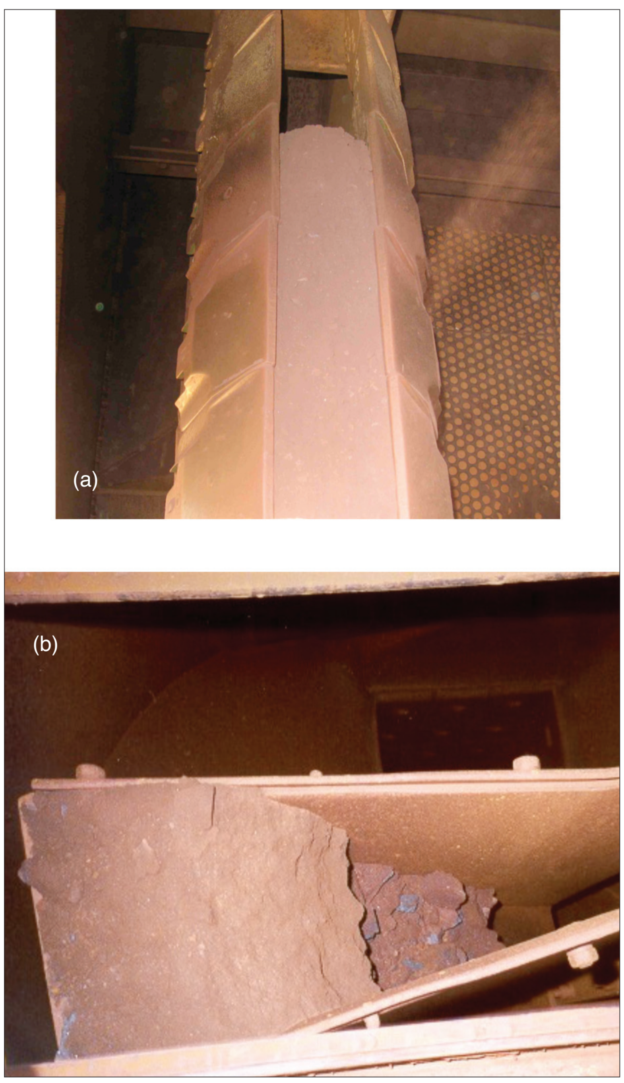

Figure 19—Examples of blocked sample cutters identified while verifying conformance with correct sampling principles for (a) a cross-stream cutter and (b) a Vezin divider

designed to meet all the requirements for correct sample preparation, in particular:

- ➤ Particle size after crushing
- ➤ Minimum sample mass requirements
- ➤ Minimal sample loss in rotary driers
- ➤ Minimal cross contamination of samples.

System verification

A well designed sampling system will facilitate inspection to verify conformance to correct design principles. For this purpose, large and easily accessible inspection hatches are required (with safety mesh installed to prevent accidental injury) for inspection of key items of equipment, including cutters, feeders, crushers, dividers, etc. The ability to monitor sampling ratio and increment mass extraction ratio also provides valuable information. The key items that need to be checked when verifying system performance include:

- ➤ Cutter speed
- ➤ Uniformity of cutter speed while cutting the ore stream
- ➤ Number of cuts
- ➤ Size and geometry of cutter apertures
- ➤ Worn and/or missing cutter lips
- ➤ Build-up and/or blockages in cutter apertures and chutes (see Figure 19)
- ➤ Reflux from cutter apertures
- ➤ Ingress of extraneous material when the cutter is parked
- ➤ Holes in chutes and bins resulting in sample loss
- ➤ Increment/sample mass
- ➤ Particle size.

Conclusion

Despite the availability of training courses, conferences, and standards on correct sampling practices, many examples of poor sampling practices can still be found in industry, usually because the responsibility for sampling is entrusted to personnel who do not fully appreciate the significance and importance of sampling. Cost is often the main driving force rather than whether the samples collected are meaningful, which seriously undermines the reliability of the final analyses. Company management needs to recognize this and act accordingly to ensure that sampling systems are well designed and provide representative samples for analysis, thereby maximizing resource utilization and minimizing financial risks.

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