RC Drilling & Sampling: Optimising the Quantity – Quality Balance*

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A B S T R A C T

In the last few years, design improvements in reverse circulation percussion (RC) drilling sampling systems have reignited the debate on the usefulness and appropriateness of samples collected by RC drilling. Where RC drilling has been sometimes criticised as being a suboptimal drilling technique for the collection of quality data for use in mineral resource estimation work, manufacturers of new RC sampling systems now claim that bad sample splitting and poor sample recovery are problems of the past.

However, having a good RC sample splitting system doesn't necessarily mean a good sample is collected. In particular, the skills of the RC driller to provide a consistent sample to the sample splitter are just as critical as the sampling system.

In this paper the authors describe cost-efficient ways to ensure the quality of drilling and sampling through well-designed standard operating procedures (SOPs), which incorporate practical and user-friendly systems. Such procedures permit RC drillers to better understand the implications of drilling actions on sample quality and facilitate better communication between the drillers and geologists.

Combining sample and drilling quality metrics with production metrics such as rig availability and rig efficiency allows the drill rig managing geologist to manage the sample quality on a daily basis. For example, real-time control plots can be used to identify when a sample quality metric is likely to be out of order (instead of the resource geologist finding such issues a week or month later). Problems identified this way can be discussed between driller and rig geologist, as they occur, and immediately corrected.

In this paper, examples of such a quality monitoring system are provided along with examples of how the system has improved metre delineation, sample recovery, sample splitting, water and dust management in exploration drilling programmes.

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INTRODUCTION

Each year, the Australian mineral industry drills between 2,000 km and 3,000 km for mineral exploration (Australian Bureau of Statistics, 2017). Of this, reverse circulation percussion (RC) drilling is the major component. Most exploration professionals consider that RC drilling can provide a good-quality sample that is cheaper and faster to collect than diamond core (DC) drilling samples, albeit that RC drilling does not provide the same level of geological information that is usually available with DC drilling.

In the last few years, design improvements in RC drilling sample-splitting systems have reignited the debate on the usefulness and appropriateness of samples collected by RC drilling. While RC drilling has been criticised by some as being a suboptimal drilling technique for the collection of quality data for use in mineral resource estimation work, others argue that bad sample splitting and poor sample recovery are problems of the past.

However, having a good RC sample splitting system doesn't necessarily mean a quality sample is collected. The ability of the RC driller to provide a consistent sample to the sample splitter are just as critical as the sampling system.

Opportunities for sampling quality improvement are often missed because:

- The quality of the sample, which is the most important aspect of the entire drilling exercise, is rarely included as a deliverable in any drilling agreement.
- The two main parties (the geologists and the drillers) often communicate poorly, due to either lack of experience and/or incomplete understanding of each other's requirements.
- There are no real-time systems in place to adequately monitor quality or performance of the drilling and sampling.

The goal of this paper, therefore, is to review how the quality of samples delivered by an RC rig can be improved through the incorporation of the latest updates in sample-splitting technology together with robust sampling procedures and processes.

THE DRILLING CONTRACT

Quality sampling starts with a good understanding between the two parties on the exploration programme requirements. Quite often, for smaller exploration companies, the drilling contract between driller and explorer is often an afterthought, a standard contract cobbled together from versions of prior projects. Most drilling contracts between larger companies and drillers span many pages, with the contract's primary focus being on safety, production management, and legal clauses.

However, a drilling contract clause that specifically discusses sample quality is seldom included. Such a clause should always be included into the drilling contract, to bring sample quality into the contract discussions, and to create a framework for discussion of the quality of the results, before the drill rig arrives on site. In this way, there is a clear understanding that the primary service to be provided is the quality of samples, not sample production rates.

A sample quality clause can be included in an appended schedule and should include expectations on:

- Sample recovery
- Sample delimitation
- Sample extraction
- Water control
- Collaring practices
- Acceptable equipment
- Hole tolerance guidelines
- Dust control
- Sample splitting accuracy
- Sample splitting precision
- Drillhole deviation

Defining sample quality constraints in a drilling contract can be challenging; however, with the use of clear and unambiguous wording, frequent communication between drillers and geologists, good monitoring systems, and an open and positive approach to maintaining sample quality, the net benefit in terms of sample quality will always be positive. The cost-benefit of the small financial investment required to implement quality sampling systems is readily demonstrated in all exploration endeavours.

COMMUNICATION

A contract agreement regarding sample quality only works well when the rig geologist and driller can work collaboratively. The geologist in charge of an RC rig may be young and inexperienced, and both geologist and drillers may lack specific training in project management communications.

A rig-management geologist may not fully understand the subtleties and intricacies of RC drilling, unless the geologist has spent significant time at an operating RC drill rig drilling in a variety of ground conditions. As such, the inexperienced geologist will not understand how subtle changes in ground conditions can affect sample quality. Unfortunately, geologists who do build up practical knowledge regarding RC drilling often end up being promoted out of the field before they can transfer this knowledge onto the next generation of young rig geologists.

Importantly, geologists and drillers need to discuss the issues that may affect sample quality before the drilling programme starts. Specifically, there needs to be a pre-agreement on what criteria define a quality sample, which comes from mostly good communication.

Initiatives that facilitate a better understanding and communication regarding exploration drilling include:

- Training of geologists before they are put in to the position of managing a drilling programme. Such training should include theory on quality assurance and control, the workings and drilling principles of an RC rig, explanations of various important components of a rig, and drilling/sample recovery situations commonly encountered in different ground conditions. There are several industry service providers that can provide this type of training if in-house expertise is unavailable.
- All drilling programmes should include:
    - An office-based commencement workshop for the drillers and geologists, where the programme objectives are explained, the expected ground conditions are discussed, and access and logistical issues are made clear. Later, in a field-based workshop, the driller should explain how the rig works and key safety issues related to the drilling process. The more detail, the better, such as demonstrating to the geologists a dry-run of a rod and run-through of some possible sampling scenarios. The driller should also collapse the rig mast so the geologists can inspect the sampling system from bit to sample bag through the whole RC sampling collection system.
    - Weekly quality meetings during the programme, where drillers and geologists meet to discuss sample quality aspects along with data and graphs of quality monitoring results.
- The implementation of a quality management system that helps facilitate communication as described further below.

RESOLVING RC SAMPLE QUALITY ISSUES

Creating a monitoring system for the quality of the samples is only possible if the sources of potential errors are understood. The following sections discuss some of the primary sources of errors.

QUALITY OF THE PRIMARY SAMPLE

As discussed above, specification of the expected quality of the primary sample is very seldom addressed in pre-programme discussions or drilling contracts. Often, geologists, when preparing post-RC-drilling reports, will prepare many pages of graphs regarding the performance of laboratory quality standards, but then fail to include a single word on the monitoring of the quality of the primary sample. At best, report discussion will include the quality of sampling from the rig splitter, with the quality of the primary sample simply implied to be "good". Importantly, the primary sample (otherwise called "the lot") is collected at the bottom of the drill string, where the hammer is breaking up rock over a designated interval.

The importance of the primary lot generation point is acknowledged in "Table 1" of the JORC Code (JORC, 2012). The first entry in Section 1 of Table 1 requires a Competent Person to discuss the quality of the primary sample. However, too many practitioners only include information on the RC sample splitting (for example the ‘field duplicate’), and frequently include information regarding laboratory preparation and analytical processes, which should be described in other subsections of Table 1. These reporting trends demonstrate that the industry is not focussing on the quality of this primary sample and to some extent there is confusion as to how to discuss the primary sample under JORC Code guidelines. The key omission here is the understanding that the largest sample errors occur at the primary sampling stage.

Mineral resource estimation (MRE) is based on interpolating or extrapolating assay results from drilling data to estimate the grades of larger volumes. The assay point data are derived from the RC subsampling, which often reflect one-metre down hole drilling intervals. Explorers not immediately familiar with the estimation process may not immediately appreciate that, for example, a 30 g fire assay result may be informing the grade estimate of a mining block with a mass of >750,000,000 g. Given these order-of-magnitude mass differences between assay results and the block size, it is intuitively important for this assay to be as representative as possible of the primary sample, meaning that the sample accuracy and precision are suitable for block grade estimates.

Sampling situations, issues and problems can be discussed using the standard nomenclature developed by Pierre Gy in the 1960s (Gy, 1979). For splitting processes the sampling errors pertinent to RC subsampling are the Extraction Error (EE), Delimitation Error (DE), and Preparation Error (PE), as discussed in the subsections below.

Sample Delimitation Errors

Ideally, the assay resulting from the subsampling and analysis of a one-metre down-hole drilling interval will be fully representative of the actual metre drilled. Usually this means that the assay result lies within what is deemed to be an acceptable variance from the true (but unknown) primary sample grade and that there has been no significant bias in the sample collection of the targeted primary sample.

Compared to diamond core (DC) drilling, RC drilling has lower boundary resolution because RC sampling on fixed intervals means that the sample often transects geological and grade estimation domain boundaries. Specifically, with DC drilling, sample intervals can be selected at key geological contacts, but with RC drilling, the sample delimitation is controlled by the regular sampling interval. As such, RC drilling may not be a suitable method for narrow tabular mineralisation.

Even when RC sampling is considered appropriate for the mineralisation under consideration, each sample is expected to be (exactly) a one-metre interval. However, if attention is not paid to the advancing drill string, a delimitation error (DE) will occur and the resulting subsampling will not represent a one-metre primary sample. The outcome of such delimitation errors is an increase in the data variability due to the difference in sample support between samples. For confidence in MRE work the assay results should reflect the true variability of the one-metre intervals, not the inflated variability that occurs when short samples are introduced in the MRE database.

DE problems are common in RC drilling programmes when:

- The metre marks are not properly delimited on the rig pull down chains and the systems in place to mark the end of a metre are based on general visual judgments by drillers or off-siders. Marks on the mast or chain are often quickly obscured by dust and/or grease and difficult to see.
- Inattention by the driller in observing the metre marks when samples are dumped to the cyclone/sampling system.
- Drilling practices exist, such as slightly over drilling the last metre of a drill rod to protect the hammer resulting in the sample support of the last-rod-sample being say 1.1 m long, while the first-rod-sample of the subsequent drill rod is 0.9 m long.

These are common issues and the resulting delimitation errors are often underestimated and ignored.

Sample Extraction Errors

As the rock is broken up at the hammer down the hole, the stream of air and sample cuttings enter the RC inner tube due to built-up air pressure in front of the bit shroud, which is designed (largely) to prevent the air from the outer tube of the RC rods from escaping between the rods and drill hole walls. The sample stream then proceeds through the sample delivery and collection system (cyclone) to end up reporting to the cyclone underflow, from where it reports to the sampling system. Ideally, all the rock fragments from a single metre of drill advance should end up in either the split sub-sample bag(s) or the splitter reject. When some part of or size fraction of the sample material does not end up reporting to the cyclone underflow and sampling system, then an Extraction Error (EE) occurs. Like the DE, the EE may create an unacceptable bias and/or inflate the variance of the MRE data set.

EE can be introduced in RC drilling through:

- **Loss to outside return**. A worn shroud, too-narrow rods, or excessively large tolerance between shroud diameter and bit diameter may lead to poor sealing of the air stream and instead of all the sample stream returning through the inner tube, some fraction is returned to surface outside the rods. A 3-mm diameter difference between bit and shroud is generally the recommended maximum tolerance for good RC sample recovery. However, some drillers intentionally set greater tolerances to prevent bogging and increase drill advance rates by 'wasting' some of the primary sample. Drillers rarely communicate this information with the rig geologists and such sample quality trade-offs should be agreed before the drillers make this decision.

- **Blowing out the hole too vigorously between rods**, resulting in hole wall cavitation and (over) delimitation error, particularly in softer rock types.

- **Lack of air pressure, worn O-rings, blown inner tubes, lack of rig compressor capacity**. Any of these conditions may result in a situation where there is insufficient air pressure to lift all the primary sample up the rod string during the metre advance. Typically, insufficient air pressure results in the primary sample being excessively re-ground and pulverised at the hammer, with sample material lost by bypassing the shroud to the outside return or excessive fines loss from the RC cyclone vortex finder.

- **Not allowing time to let samples clear the system.** At the end of each metre, time is required for all sample cuttings to travel from the bit through the inner tube to the sampling system. Removing the sample bags right on the time when the metre mark is reached means some sample from that interval will still be travelling to surface and will inevitably end up in the next sample. One solution is to pause briefly at the end of each sample interval to allow the sample to properly clear the system before the next metre is drilled. The pause interval needs be increased with the depth of hole and a simple calculation of air flow rates, pipe diameters and depth can give an indication of the clearance time required. However, this requirement will, of course, reduce the average drill hole advance and is one of the more contentious issues that should be dealt with at the drilling contract stage. Some explorers' operating procedures require the driller to pause for up to 10 to 15 seconds at the end of each metre sampling interval and to "pull the rods off bottom" and let the hammer "fire out". This process means that the RC hammer will lose contact with the bottom of the hole and will quickly lock and the air flow should clear through the sample system. However, some drillers will not like to execute this procedure because:

    - According to some, the process can damage the RC hammer or the bit rim ring as the bit design is to preferably hammer against some support, not for the piston to fire against open air.

    - When the bit is locked and not hammering, excessive air is lost through outside return. When the bit is placed back at the bottom of the hole, the pressure must be re-established at the cost of increased diesel consumption.

    - When the hammer face is placed back at the bottom of the hole, unplanned hole deviation may occur, especially in the case of using a large shroud tolerance.

Some drillers prefer to let the hammer fire out at the end of each sampling interval but keep the bit rested on the bottom to keep the air pressure high and minimise the risk of bit damage. Significant experience is required to get this right, and not all drillers seem to agree on best practice here.

<u>Wet Drilling: Sample Preparation Errors</u>

RC sampling is designed to occur under dry ground conditions. Compressed air powers the hammer and carries the drill cuttings to surface through the inner tubes in the RC drill string. Ideally, injecting very high pressure air down the hole creates an air pocket ahead of the drill shroud, so that each drilling interval is kept dry, even if the sampling interval is below the groundwater table.

However, when a new rod needs to be added and the bit is below the water table, the temporary reduction in air pressure may result in flooding of the hole with groundwater. In this situation, it is now common practice to first use a blow-down valve to clear water from the hole through the outside return, by directing a blast of high pressure air down both inner and outer tubes. Drilling can then re-commence under dry drilling conditions.

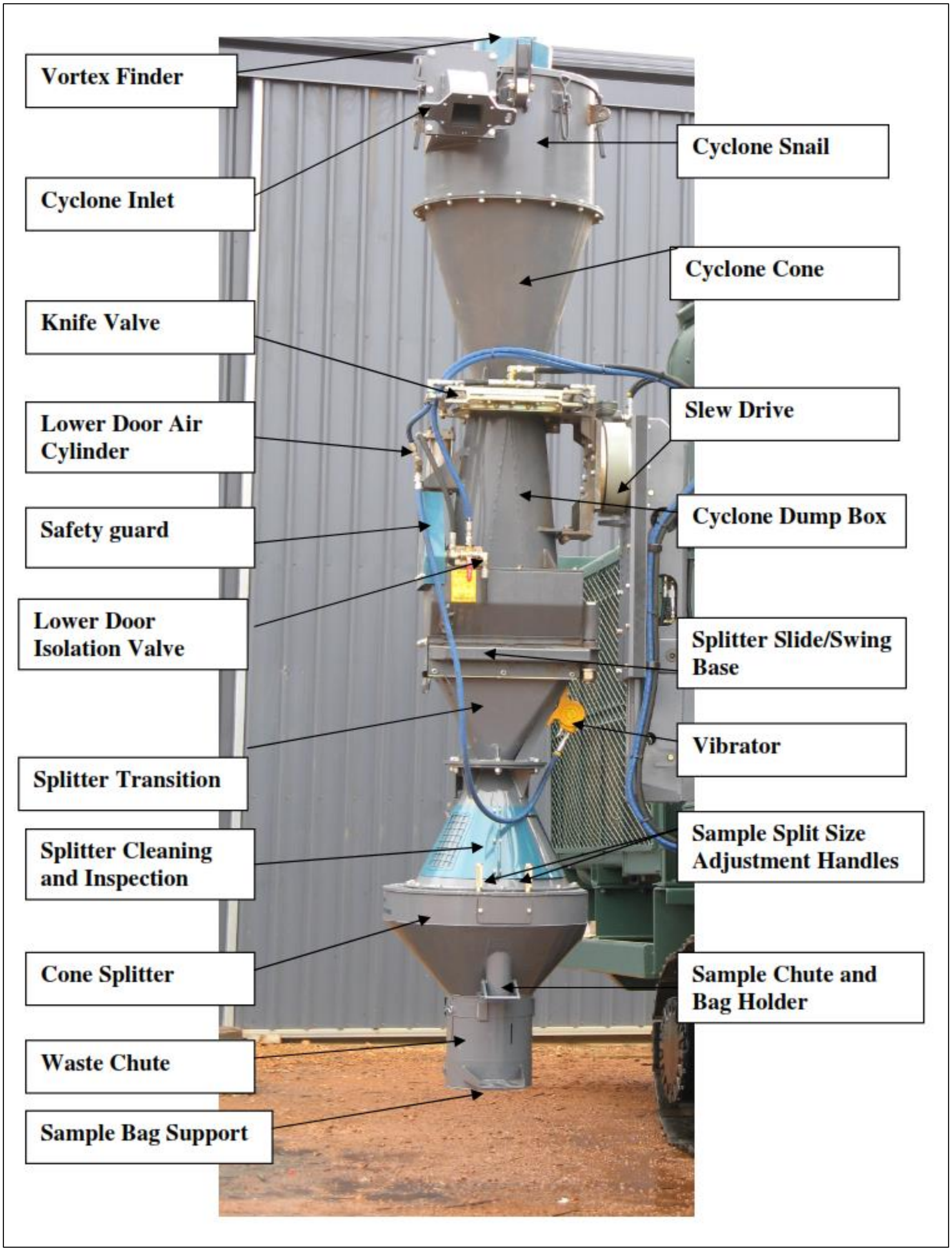


Figure 1 A classic rig-mounted static cone sampling tower

Even with good-practice drilling, it is inevitable that water will sometimes enter the hole when water-saturated broken-ground conditions are encountered, and/or the available air pressure is momentarily insufficient to drive water away from the advancing bit. While it may be possible to increase air pressure to keep the hole dry there is a risk that a too-high pressure could blow out the collar seal and the hole would have to be abandoned.

In the case of water inflow due to local conditions of broken ground, it may be possible to drill beyond the broken zone (producing wet samples) and then continue dry drilling as normal. In such situations, the geologists and drillers need make sure that the sampling system is appropriately cleaned of mud build-ups at the first available rod-change, and they should note on the electronic logging sheets that the condition of the sample collected is likely to be of poor or suspect quality.

In the case where significant continuous water inflows are encountered, the driller may need to secure collars by cementing them. This adds significantly to time and cost, and the benefit does not always outweigh the cost of having the occasional wet sample returned from the bottom of some drill holes. This is where discussion regarding expected ground conditions (particularly expected water inflows) before the start of a drill programme and each drill hole are valuable.

Even though some authors consider that good quality sampling is possible under wet drilling conditions (Carswell and Sutton, 2014), preparation errors (PEs) always occur when RC drilling happens under wet conditions due to loss of fines in the slurry water. The best solution here is to switch to DC drilling when RC drilling is clearly not meeting quality sample requirements.

QUALITY OF THE SECONDARY SAMPLE (RIG SPLIT SAMPLE)

After the sample cuttings have passed through the inner tubes and the sampling hose, the sample stream exits the RC cyclone to the sample splitting system. The primary sample mass then needs to be reduced to provide the laboratory with a manageable sample mass from the primary sample, which is typically 35 kg to 45 kg for one-metre drilling interval. A manageable mass is typically in the range of 2 kg to 4 kg, although some mineralisation types require split samples larger than 4 kg.

There are a variety of RC subsampling systems on the market, and all require a cyclone to separate the particulate sample cuttings from the high-pressure air prior to subsampling (Figure 1). A cyclone is effectively a particle size -and density separation device and the micron-sized fines from the sample stream are lost from the top of the cyclone unless specific measures are implemented to catch these fines. The coarse particles exit at the base of the cyclone.

The sample cuttings are usually collected into a cyclone dump box before this primary lot is gravity-fed into the splitter. Splitters typically used in RC subsampling are commonly static cones, rotary cones, or tiered riffle splitters. These sub-sample splitting systems may be mounted on the drill rig, on a separate trailer, or simply mounted on the ground as separate cyclone and splitting devices.

In the first sample splitting stage, several sampling errors can and usually do occur. The main argument against the use of RC drilling for sample collection for MRE work is that even under optimum conditions, a sample bias will always be present when sample fines are lost from the sample collection system. Conventional sampling systems such as the popular static cone splitters produce a potentially biased sample, due to the fact that it is very difficult to make sure that material is presented to the splitter consistently.

Sample Delimitation Errors

Sample delimitation errors are common on both static cone and tiered riffle splitters. The designs of both these splitters, as per the theory of sampling, are incorrect, particularly the static cone. Notwithstanding the incorrect designs, these splitters can also introduce additional biases due to improper feeding of the sample stream to the splitter and state and maintenance of the equipment.

For a static cone splitter to deliver a correct sample the sample stream must be uniformly distributed when delivered to top of cone, as only one part of the sample stream is directed to the laboratory subsample. A uniform distribution from a cyclone dump-box is problematic regardless of the dump-box door design (butterfly, sliding, single-flap) as the sample collected in the dump box will be delivered inconsistently to the cone, producing a DE and a bias, particularly if the material in the dump box is segregated. Additional bias will occur if the splitting system is not perfectly level. Commonly, regardless of how the sampling system is mounted, static cone splitters have a high sub-sample mass variability resulting in a potential systematic grade bias.

For tiered riffle splitters, most sample feed designs are incorrect with designs releasing material too quickly onto one side of the riffle splitter, choking the device and introducing biases due to sifting segregation. Almost all riffle splitters mounted on an RC sampling system are tiered, comprising three or four tiers of riffles. Tiered riffle splitters assume mixing of material between tiers, which is an unrealistic assumption, and the subsamples are therefore incorrectly delimited. They are also highly sensitive to long-axis levelling. Any tilt results in uneven presentation of the flow from the exit chute of one riffle onto the vane below. This is exacerbated from level to level, and a very slight tilt can induce a large departure (bias) in split proportion away from the theoretical mass. If flow segregation develops downwards through the chutes, then the mass bias will lead to grade bias also.

Sample delimitation errors also occur with incorrect operating procedures of the equipment. Often, after years of usage, the sample shoots on the splitter, which regulate the size of the sample, may be blocked or damaged. Using a crowbar or other device to force the cone splitter sample shoot sliders to move may lead to bent chute blades and a biased sample. The duplicate cone splitter chutes are commonly operated like scissors, and uneven setup may result in the two chutes giving a different split weight. Older sampling systems that are not well-maintained may often have either the knife valve or the lower cyclone dump box doors stuck and drillers may drill with these doors open. This practice will result in sample segregation of coarse and fine particles as the vortex airflow created in the cyclone will likely generate a preferential path for the material, with the result being a more substantial bias of one side of the splitter over the other.

Geologists need to communicate clearly with the drillers before contract commencement as to what sample systems are to be used and how the systems are to be maintained. The geologist must inspect the systems before the rigs and sampling systems are mobilised to site and should seek independent expert advice on mechanical issues that they may not have the skills to assess. There should also be a clear understanding on how sampling systems are to be used.

Sample delimitation is the primary focus for improvement of a new generation of RC sampling systems, such as the Metzke SplitterTM (Metzke, 2017), the Corporaal TruSplitTM (Corporaal, 2017), and the Progradex PGXTM sampling systems (Progradex, 2017). Such systems come with a price and before they are widely adopted and further fine-tuned by the industry, it pays for the geologist to match the purpose of the programme with the targeted quality of the sample: it may not be a problem running a standard cone splitter for a greenfields base-metal drilling programme, but a coarse gold resource definition drill-out will require optimum sample quality control.

Sample Extraction Errors

In common with the primary sample, extraction errors occur often at the splitting stage. The following errors occur commonly and should be avoided where possible:

- **Loss of sample as dust.** As discussed above, dust loss is the main sampling flaw in RC drilling. The RC drill bit pulverises the sample at the bottom of the hole and a significant amount of this material travels up the sampling system as very fine material, smaller than 100 µm. As it enters the cyclone, the larger particles will travel down in the cyclone but a significant mass of dust will escape out of the top of the cyclone, unless measures are taken to collect this material (Figure 1). In styles of mineralisation where the valuable material is preferentially contained (or depleted) in fines, fines loss may significantly bias the samples.
  There are four ways to deal with dust. Each has its benefits and drawbacks:
    - Bulk dust collection can be done with dust sampling tools that are linked in with the normal sampling mechanism. The problem with this approach is that the dust collected cannot be attributed to a specific metre interval, and as such, assaying the dust component only gives a post-sampling insight into the level of bias occurring due to dust loss.
    - Metre-specific dust collection, which requires a specialised sampling system such as the Progradex sampler, which collects the cyclone dust for each sampling interval with the rest of the sample. While this is theoretically a good solution, the sampler is relatively expensive and mechanically complex,

leading to it currently not being widely adopted by exploration drilling contractors.

  - Dust suppression, which involves spraying the dusted air with a water mist as it enters the sampling system. The concept here is to introduce sufficient moisture to make sure that the fine particles agglomerate and create particles heavy enough to gravitate through the cyclone into the splitter, but to not cause particles to stick to the cyclone lining and other parts of the sampling system. As such, dust suppression does not always meet the concept idea, and the geologists need to be aware of the limitations and risks. Geologists need to talk to drillers to find out how much moisture they are applying and inspect the sampling system for build-up and clogging at the end of each rod drilled. Due to design flaws or other technical problems, regulation of moisture induction on a rig is sometimes difficult to get right, resulting in either too much or too little suppression. Such information is very rarely communicated with the geologist.

  - Slurry creation, which involves adding sufficient water to the return sample stream to create a slurry of material, which can be sub sampled using a correct slurry splitting device such as a Vezin-style sampler and the Metzke rotary splitter. However, this then creates the problem of dealing with wet samples, which must be dried before further sample preparation, with possible loss of fines in the slurry water draining from calico bags if used, or possible losses in flocculation/decanting process, if used.

- **Sample left behind.** As mentioned above, excessive dust control water, wet drilling, or drilling sticky materials may lead to material adhering to the walls of the sampling system. This means that some sample is left behind and doesn't end up in the sample bag, which can lead to worse biases when sample build up blocks up the sample system passages. A good indicator of the degree of sample build-up is the presence and amount of layer-cake material that falls to the ground below and around the splitter, after the device has been inspected and scraped clean at rod change.

<u>Sample Preparation Errors</u>

The geologist should be aware of the common preparation errors that can occur with sample splitting. Notably:

- **Contamination between samples.** Sampling systems get clogged up due to the presence of wet material, which causes contamination between samples. And samples cross-contaminate if proper metre delimitation is not adhered to (e.g. the driller not pausing in between metres, see above)

- **Preparation errors due to design flaws.** Some splitting systems are not designed properly, for instance the use of wide-rimmed sample chute edges instead of knife-edged ones (creating sample build-up and cross-contamination between samples), or single-flap valves to open the cyclone dump box (not allowing the sample to fall over the splitter from a central point and uniformly).

- **Preparation errors due to system meddling.** Ad hoc solutions to fix problems with sampling systems often create sample preparation errors. For example, changing the cyclone airflow by restricting it or otherwise modifying it, or not using the cyclone dump box the way it is intend to, all can cause errors.

- **Preparation errors due to mishandling of the sample.** Off-siders should take care when removing the calico sample bags from the sample chutes to make sure that material from large bags doesn't spill. Each off-sider should follow the same process when handling the sample bags.

- **Preparation errors due to incorrect sample bags/numbers.** For example, using the incorrect sample bag so that the sample is assigned to the wrong depth. This requires diligent checking and cross-checking during drilling to ensure that the samples are in the correct order and that the correct bags are being used by the drillers. Bar-coding of sample bags with bar-code readers used to ensure that the correct sample bags/numbers are being used is one method (albeit expensive and labour-intensive) of minimising these types of errors.

Recent developments in sample splitting for RC rigs include the development of systems that can collect the entire sample, including the fine dust, in a theoretically sound manner (the Progradex sampling system (Progradex, 2017)), as well as systems that are less prone to delimitation errors and can deal with wet samples (Metzke Splitter (Metzke, 2017)).

A PRACTICAL QUALITY ASSURANCE AND QUALITY CONTROL SYSTEM FOR RC DRILLING

QUALITY ASSURANCE

The most cost effective way to reduce sampling errors is for geologists and drillers to understand how sampling errors occur and then prevent the errors by implementing well-designed quality assurance (QA) processes. As mentioned previously, drillers and geologists should discuss the quality issues mentioned above and include expectations in the drilling contracts. Good communication and discussion of the various sources of errors should happen before the drilling, so that all parties understand the expectations, as well as during the drilling. An ongoing discussion is required to keep refining the quality framework.

Drill contractors will aim to prepare the lowest cost bid to win a drilling tender and geologists need to consider that such bids may not factor in high sample quality unless the drillers are informed of the specific quality requirements before the bid is submitted. Well-designed standard operating procedures (SOPs) can be used as a guideline for expectations on sample quality, and can ensure that everyone in the team, from rig geologists to field technicians, understands how the various tools and practices work.

QUALITY CONTROL

Good QA is about error prevention, but a good quality control (QC) system is also required to correct errors as they occur. QC tools include the checks and balances that are used to measure the performance of the sampling system with a feedback loop for changes/improvements to be implemented as the sampling process is happening. For instance, at the laboratory, where the QC concept is well-ingrained, such tools include the insertion of standards, blanks and duplicates, so that process control can be monitored, corrected as necessary and kept as a record that the laboratory assaying process are always in control.

The same principle can be applied to RC drilling, where subsample and/or reject bag masses can be used to give important information on sampling consistency. Most delimitation and extraction errors influence the subsample weights and therefore can be used as a good proxy for drilling quality.

Note that the purpose of QC is real-time error correction, not post-drilling reviews weeks or months after the process has finished. Therefore, the bag weight data needs to be controlled as the rig is drilling, as well as being reviewed at least daily, rather than handing the result over for review at the end of the programme.

QC on the Primary Sample

Assuming relatively uniform rock types and density, dry drilling and a uniform hole diameter, each drilled metre should result in the same expected sample mass. If that mass is higher or lower than the expected mass, then a procedural drilling or a sampling error has likely occurred. For instance, if the mass of a metre of sample is 35 kg instead of an expected 40 kg, then it is highly likely the interval was not properly delimited, or that there has been a substantial loss of sample during extraction. However, for the case of a 39 kg sample return, it is likely that mass variance is simply an acceptable (normal) random error that can be expected even in a well-controlled physical process.

An effective QC process is to plot the total mass of each successive metre sample on a control plot, in a similar manner to the typical laboratory certified reference material control. Control limit lines can then be added to the plot using a moving range (MR) approach (Sterk, 2015). Samples having masses that plot outside the upper and lower control limits are outliers and indicate that something in the sampling process is likely to be out of order and need to be investigated. Equally, two out of the last three points above/below two MR-standard deviations, four out of the last five points above/below one MR-standard deviations or eight consecutive points on one side of the mean or target value, all indicate that something is likely to be wrong with the sampling system.

The approach described above implicitly assumes that the errors in weights are normally distributed due to a random process. However, a variety of rock types are encountered in drilling a hole with both fresh and weathered conditions, changing bit sizes down the hole, and samples can also be damp or wet, depending on ground conditions. As such, data in the sample mass control plots should be automatically corrected for known or assumed densities, bit diameter changes, and wet samples are excluded from the analysis. The primary samples are weighed in total, including the bulk plastic bag and original and duplicate calico sampling bags. The data is entered into the control spreadsheet by a sampling technician as the samples are collected at the rig, so that there is a real-time monitoring process. The technician will enter any relevant comments, so that it is clear to end users of the data that a certain sample mass was deemed defective for a specific reason, such as water in the hole, a blow-out or cave-in, collar debris re-drill, etc. and, that the data should be excluded for MRE work.

Figure 2 is an example of a sample mass control plot where a "normal" pattern of variability can be observed in the wavering blue line in the top graph of the primary sample bag masses. The weathered rock sampling intervals are not included in this analysis but can be treated separately if required. In this example the hole was mostly dry, so not many wet samples were excluded from the analysis. A lot of this mass variance may well be "reasonably expected" for this type of drilling, and the results are consistent with largely random controlled variability. However, the samples automatically highlighted with yellow circles in Figure 2 indicate sample masses that are statistically unlikely due to just random variability, and such samples need investigation and explanation. In this example, the corrective actions a rig geologist should implement are: firstly a discussion with the driller to learn if they are one-off causes due to the drilling approach; and, if no cause can be found, drilling should continue under more scrutiny regarding sample quality. If a second outlier deviation occurs, this signals a need to stop drilling and inspect the drilling and sampling system.

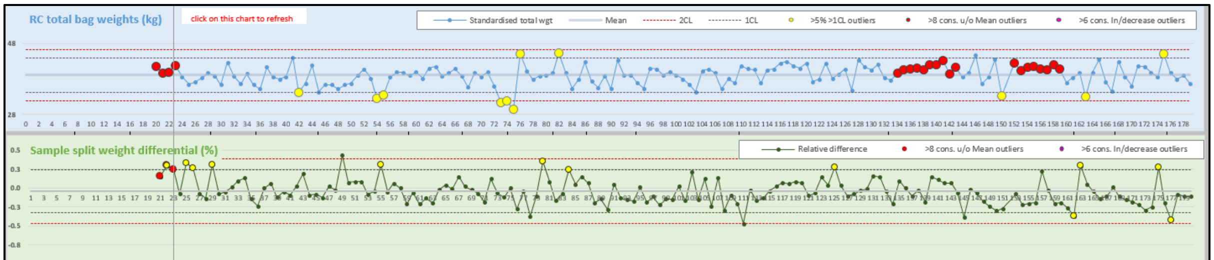
Sample mass control plots also permit the monitoring of trends. A trend of higher sample masses for samples collected from the last sample in a drill rod run is common, which may indicate delimitation errors, as discussed previously in this paper. Any mass trends can be further investigated by group-averaging the masses of the1st, 2nd, 3rd, 4th, 5th, and 6th metre of every rod and plotting these as a bar graph, as depicted in Figure 3. In this example, there is a significant metre-delimitation problem that needs to be resolved, as metres are getting progressively heavier towards the end of each rod. In the authors' experience, this is a frequently observed issue.

With regards to the expected mass accuracy of each primary sample, the total estimated recovery per metre can be calculated, and where this metric is higher or lower than expected, this mass bias should be discussed with the driller. This may identify issues such as too much material being lost to outside return from excessive shroud tolerance or dust losses from the top of the cyclone. An estimated total sample recovery of 90% or better should be routinely achievable.

<u>QC on the Rig Split Sample</u>

The mass monitoring system to check for delimitation and extraction errors can also be used to monitor the primary lot sub-samples to provide a QC system for the sample splitting process. Ideally, a splitter should show zero mass difference between the routinely collected sample (the original) and a duplicate sample collected from the same primary lot. If the splitter is providing uneven mass splits, then the difference in the routine-duplicate subsample mass will be highly variable.

The routine-duplicate sample mass differences can be measured and plotted in exactly the same way as the primary lot sample masses. Any samples having masses outside the control lines can signal splitting issues such as sample hang-ups, blockages and/or misalignment of the splitter. Real-time monitoring of



hole_id	depth_from	depth_to	interval	total_wgt_kg	wgt_original_split_kg	wgt_duplicate_split_kg	scale_type	date_weighed	weighed_by	sample_condition	lith_code	bit_diameter_mm	comments	theoretical weight check	standardised_total_wgt	sheet validation	SSD	theoretical_total_wgt	recovery_pct
THRC283	63	64	1	45.90	5.10	5.20	ti	4/06/17	SN	D	MG	146			41.07	OK	3.09	52.52	87%
THRC283	64	65	1	42.80	4.85	4.65	ti	4/06/17	SN	D	MG	146			38.30	OK	3.09	52.52	81%
THRC283	65	66	1	43.90	4.80	4.85	ti	4/06/17	SN	D	MG	146			39.28	OK	3.09	52.52	84%
THRC283	66	67	1	45.20	5.65	4.85	ti	4/06/17	SN	D	MG	146			40.45	OK	3.09	52.52	86%
THRC283	67	68	1	42.90	4.60	4.50	ti	4/06/17	SN	D	MG	146			38.39	OK	3.09	52.52	82%
THRC283	68	69	1	39.40	4.25	4.35	ti	4/06/17	SN	D	MG	146			35.26	OK	3.09	52.52	75%
THRC283	69	70	1	44.00	4.65	5.00	ti	4/06/17	SN	D	MG	146			39.37	OK	3.09	52.52	84%
THRC283	70	71	1	42.70	4.30	5.15	ti	4/06/17	SN	D	MG	146			38.21	OK	3.09	52.52	81%
THRC283	71	72	1	37.20	4.20	3.70	ti	4/06/17	SN	D	GRA	146			39.47	OK	2.61	44.29	84%
THRC283	72	73	1	34.00	3.75	4.00	ti	4/06/17	SN	D	LGR	146			35.55	OK	2.65	44.95	76%
THRC283	73	74	1	34.60	3.90	4.40	ti	4/06/17	SN	D	MG	146		total wgt > 25% from theor. wgt	30.96	OK	3.09	52.52	66%
THRC283	74	75	1	35.05	3.60	3.60	ti	4/06/17	SN	D	MG	146		total wgt > 25% from theor. wgt	31.36	OK	3.09	52.52	67%
THRC283	75	76	1	32.30	4.20	5.55	ti	4/06/17	SN	D	MG	146		total wgt > 25% from theor. wgt	28.90	OK	3.09	52.52	61%
THRC283	76	77	1	50.00	5.30	5.50	ti	4/06/17	SN	D	MG	146			44.74	OK	3.09	52.52	95%
THRC283	77	78	1	44.60	3.85	5.60	ti	4/06/17	SN	D	MG	146			39.91	OK	3.09	52.52	85%
THRC283	78	79	1	41.75	4.25	4.75	ti	4/06/17	SN	D	MG	146			37.36	OK	3.09	52.52	79%
THRC283	79	80	1	43.00	5.60	3.90	ti	4/06/17	SN	D	MG	146			38.48	OK	3.09	52.52	82%
THRC283	80	81	1	38.10	4.80	4.40	ti	4/06/17	SN	D	FG	146			38.53	OK	2.74	46.47	82%
THRC283	81	82	1	38.80	4.45	5.25	ti	4/06/17	SN	D	FG	146			39.24	OK	2.74	46.47	83%
THRC283	82	83	1	44.35	4.35	4.70	ti	4/06/17	SN	D	FG	146			44.85	OK	2.74	46.47	95%
THRC283	83	84	1	44.00	4.60	3.60	ti	4/06/17	SN	D	MG	146			39.37	OK	3.09	52.52	84%
THRC283	84	85	1	33.40	4.80	4.55	ti	4/06/17	SN	D	LGR	146		total wgt > 25% from theor. wgt	34.92	OK	2.65	44.95	74%
THRC283	85	86	1	41.90	4.65	4.00	ti	4/06/17	SN	D	MG	146			37.49	OK	3.09	52.52	80%
THRC283	86	87	1	40.50	5.25	4.90	ti	4/06/17	SN	D	LGR	146			42.34	OK	2.65	44.95	90%

Figure 2 RSC quality control sheet for RC drilling sample mass data. The first graph (blue shade) is a plot of primary sample masses on the vertical axis plotted against time sequence. The second graph (green shade) is a plot of the relative difference weights between the routine and duplicate samples. The tabulation below the charts is a record of the data collected and includes recovery estimates adjusted for each rock type and other systematic variations expected in the drill hole. Red and yellow dots identify special cause variation (too many points on one side of the mean and points outside warning lines resp.). Explanation in text.

the mass difference data offers the opportunity to make immediate corrections, and improve the quality of the sample splitting throughout the drilling programme or drill hole under consideration.

In the example shown in Figure 2, the split-mass data reveals some suspect trends, with two periods having sample split masses that are clearly biased. These cases signalled the need to open up and clean the sampling system. Again, the sampling technician included comments in the data input spreadsheet so that end users of the data (such as the resource geologist) can decide whether to exclude or increase the risk weighting of these biased samples in MRE work.

Note that the split mass QC process requires the collection of a duplicate sample for each metre drilled. However, not all the duplicates need to be submitted to the laboratory, only a designated proportion of duplicates need to be submitted, and the duplicates can be selected from likely mineralised material rather than collecting duplicates from obvious waste zones. The additional duplicates collected do have the cost of an additional subsample calico bag but this approach creates a resource of additional duplicates that have already been split using the same splitting tool and under the same conditions as the original samples. Logistically, this approach has advantages for future resampling, especially when the sample rejects are discarded. As such, the small extra cost of the calico bag and cost in managing those extra bags is therefore easily justified.

Every QC system comes with its limitations and QC monitoring should not be used as a tool designed to immediately criticize a drillers skill and performance. In the authors' experience, most drillers are interested in understanding what impacts their actions have on the sample quality, and are keen to improve their drilling skills with the use of a positive feedback system. It is good practice to provide drillers with the control plots from each day of drilling, so they can review and discuss the results with the geologist before the start of their next shift as well at weekly toolbox meetings.

MEASURING PRODUCTION VS QUALITY

Given the trade-off between quality and production, it is useful to capture this balance in graphical format, so that better decisions can be made by drillers and geologists on a daily basis.

From the drilling contractors' perspective, RC drilling performance is measured as the total metres drilled per day. This metric is a measure of the drillers' general efficiency, including the ability to get ready for the day, conduct their pre-checks, have fuel and water solutions at hand and not cause down-time, handle the ground conditions, and drill metres. Useful efficiency metrics include:

- Daily Drilling Efficiency ratio, measured as:

$$100\% - \frac{(Work\ Time - Down\ Time - Standby\ Time - Drilling\ Time)}{(Work\ Time - Down\ Time - Standby\ Time)} \times 100\%$$

- Daily Utilisation Total, measured as:

$$100\% - \frac{(Work\ Time - Down\ Time - Standby\ Time)}{(Work\ Time - Down\ Time)} \times 100\%$$

- Daily Availability, measured as:

$$100\% - \frac{(Work\ Time - Down\ Time)}{(Work\ Time)} \times 100\%$$

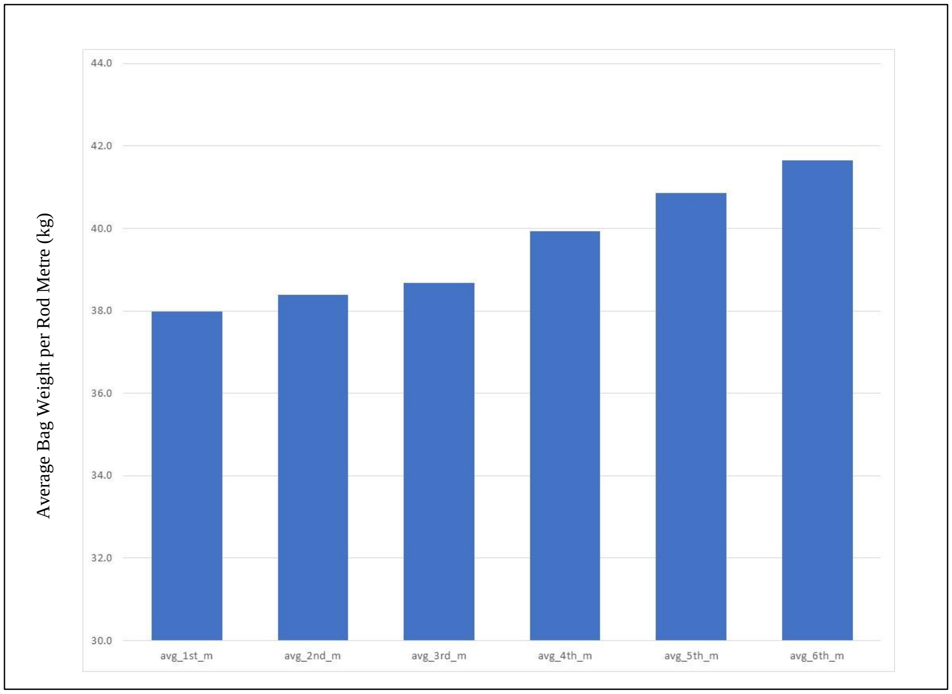


Figure 3 Average bag weights of 1st, 2nd, 3rd, 4th, 5th and 6th metre of each rod for one day of drilling (single driller on single rig)

However, when comparing quality of drilling with production, it is best to look at production during active drilling hours only, being the total metres drilled when the RC hammer is operating (often called "penetration rate"). In particular, a focus on drill penetration rate gives a measure of how too-rapid advance rates may be adversely affecting sampling quality for a given set of ground conditions.

Quality monitoring can be presented using time or depth graphs of the precision and accuracy on both primary and rig split samples. There are five quality metrics that can be used to compare against the metres/active drilling production ratio:

- Precision of all bag masses, as an indicator of the control on delimitation and extraction errors on the primary sample, measured by the standard deviation divided by the mean for all dry, fresh and density-corrected data for the time period.
- Precision of average 1st, 2nd, 3rd, 4th, 5th and 6th metre of every rod as an indicator of the control on delimitation errors on the primary sample (e.g. "delimitation performance"). This is measured by the standard deviation divided by the mean for the overall average of, respectively, the 1st, 2nd, 3rd, 4th, 5th and 6th metre of every rod for the time period.
- Overall recovery for the day as a measure of accuracy of the primary sample, measured by the ratio of all dry, fresh and density-corrected weights over the theoretical weight for the time period.
- Precision of sample split masses, as an indicator of the control on delimitation and extraction errors on the rig split sample, measured by the standard deviation divided by the mean for all mass differences for the time period.
- Overall bias of the difference between original and duplicate sample masses as a measure of accuracy of the rig split sample, measured by the average of all split weight differences.

Examples of control plots are shown in Figure 4, Figure 5, and Figure 6.

Figure 4 is a of the delimitation precision of the primary sample over time for one driller. The clustered light-to-dark-blue lines are the average masses for the 1st, 2nd, 3rd, 4th, 5th and 6th metre of every rod for each day. For the 10-day period between 14 to 24 May, the 6th sample of each rod was always the heaviest and the second metre the lightest. For the period between 6 April and 4 May rod-interval-sample-mass pattern was random, and lines for each sample sequence are clustered more closely together indicating the preferred target variability between sequential samples on each rod. The orange line in Figure 4 represents the principal delimitation precision, with low precision numbers representing better quality (e.g. low variance is desirable). Again, the period between 6 April and 4 May stands out as period of good sample quality because of the low precision. Discussions with the drillers identified that some of the quality issues related to the rig conditions (rigs were changed over on the 10th of May) as well as some ground condition issues. One of the issues identified by this graph (and using the plot in Figure 3) was that the metre marks used to identify drilling advance intervals were incorrectly placed on one of the drill rigs.

Figure 5 is a plot of the delimitation and extraction precision, and the accuracy of the rig split sample over time. The blue points on the background of the plot are the routine-duplicate mass difference values plotted on the vertical axis, date on the horizontal axis. The red dotted line is a 20-point moving average for the pair mass difference data.

The plot reveals at least three periods where average mass differed significantly, as indicated by step changes in the average mass line (black) in Figure 5. In the first period the mass difference bias is ≈ +400 g, with the duplicate always heavier than the routine split, which was targeted to be 5 kg. As such, the +400 g difference represented a relative bias of ≈ +8%. The second period, started on 29 March when the sample splitting device was changed from a static cone splitter (used for the first period) to a Metzke Splitter. During commissioning of this unit, the mass difference plot revealed that the new sampling unit produced a negative bias between routine and duplicate samples of ≈ -400 g up until 10 April. Following some small engineering modifications and with increasing experience with the new sampling system, the split masses returned on average to zero difference, and sample splitting continued without bias.

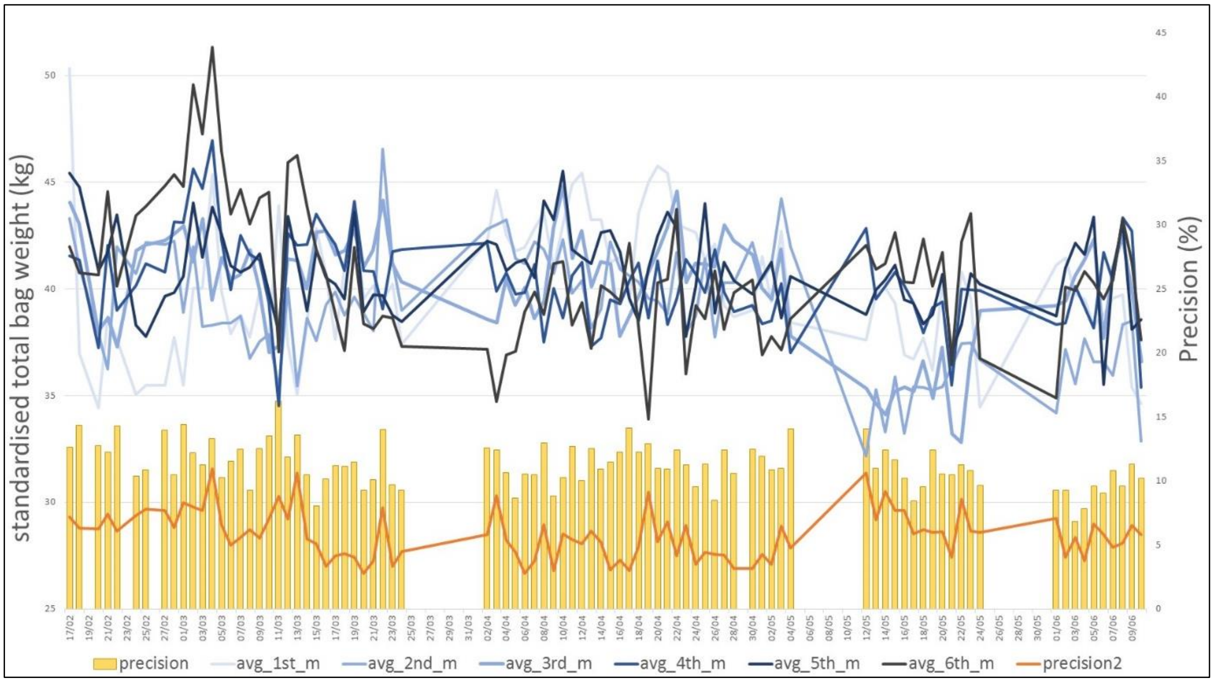


Figure 4 Delimitation precision of the primary sample over time. See text for explanation

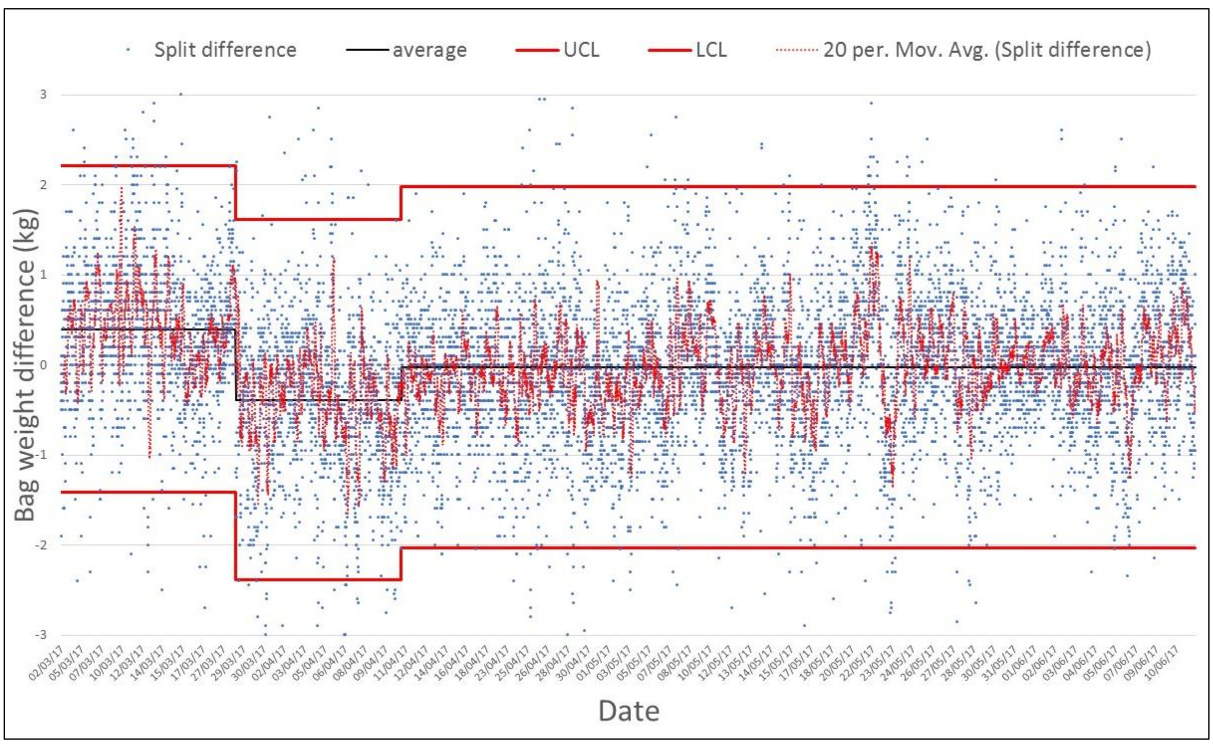


Figure 5 Accuracy and Delimitation & Extraction Precision of the rig split over time. See text for explanation

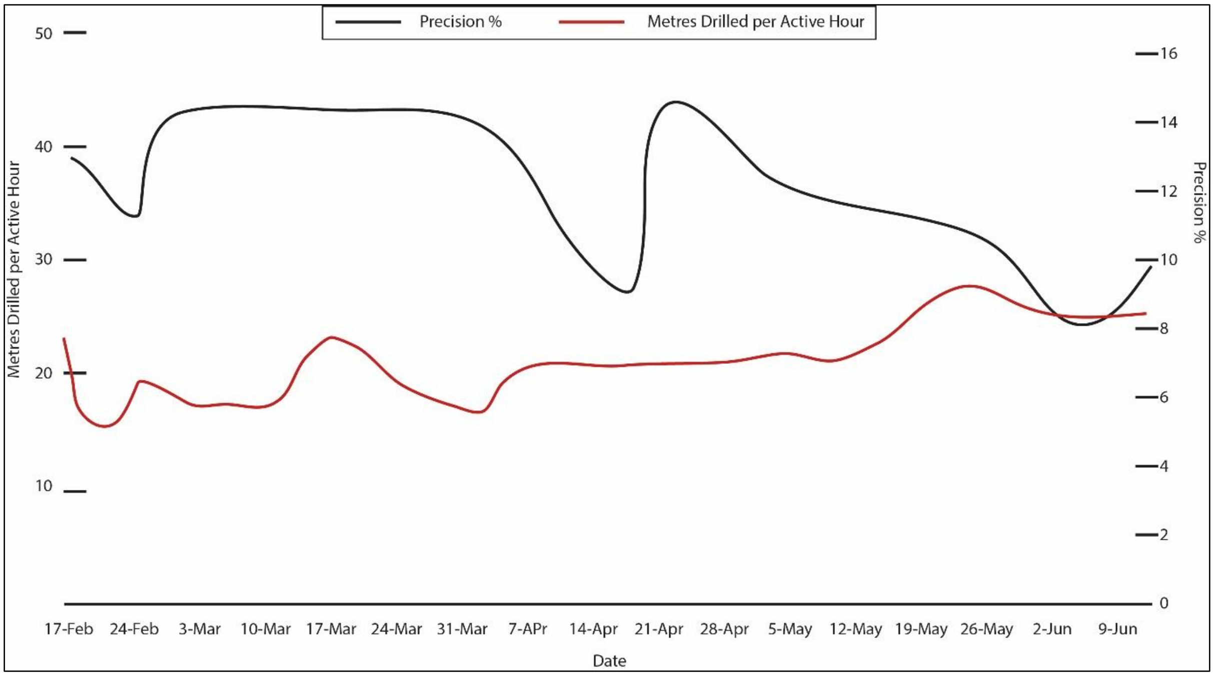


Figure 6 Delimitation & Extraction Precision% vs Metre/Active Drilling Hours. See text for explanation

Figure 6 is a plot of the primary delimitation precision against the metres/active drilling hour for a drill rig. Note how the drilling production improves towards the end of the programme from 18-22 m/active hour to 22-24 m/active hour, with quality improving in parallel from 12-14% precision to 8-10% precision. Both metrics spike upwards after 21 April, when a drilling crew changeover occurs and a new driller takes over. However, the chart then reveals that with time and feedback the new driller learns how to deal with the ground conditions and returned both metrics to levels of good production and good sampling precision.

SUMMARY AND CONCLUSIONS

RC drilling is usually subject to a range of sampling errors that occur in the primary or sample splitting stage. Understanding the source of these errors and putting systems in place is the first point of call for a robust system to improve the overall quality of the RC sample.

A QC system that is based on sample primary sample masses and secondary sample mass difference for replicated splits from the primary lot can identify when delimitation and extraction errors may be occurring on a real-time basis. When plots of these metrics are prepared as easy-to-interpret communication tools for geologists and drillers, constructive discussions around the results improves both sample quality and drill production rates.

When these types of processes are implemented in RC drilling programmes, the resulting data can be considered as high-quality for downstream MRE work.

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