A comparison between conventional blast hole sampling and diamond core drilling for copper grade at the Antapaccay mine

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Even though the sampling technique result in potentially biased samples with poor precision of the metal grade and are classified as specimens and not samples, the manual sampling of rotary percussion blast hole chips is still widely performed in the industry for operational grade control purposes.

The objectives of this investigation are to estimate the precision and "bias" of manual sampling by comparing the copper grade results of fifteen (15) diamond drill core samples versus fifteen (15) rotary percussion blast hole drilling chip samples. This also includes the determination of a practical manual sampling template with the highest precision to provide an understanding of the distribution of the copper content within the cone of blast hole chips. The contouring plots of the copper grades provides the selection of the best fit-for-purpose template with regards precision and operational resourcing requirements. The diamond drill core samples take into account the Increment Delimitation Error (IDE) and Increment Extraction Error (IEE) and therefore can be considered as reference samples for the purpose of this review.

INTRODUCTION

Production and service processes need to be periodically evaluated by suitable indicators, not only for its control, but for its improvement over time. But what affects these processes? Deming quoted "*if I had to reduce my message to managers to just a few words, I would say it all had to do with reducing variation*"[1]. Thus, variation must be measured, controlled and reduced through improvements in technology, process design and training of people.

Sampling is a critical issue throughout the mine value chain, where it includes the sampling of both *in situ* and broken material. In all cases, the aim is to obtain a representative sample to accurately describe the material in question[2].

A sample might be described as being representative when it results in acceptable levels of both bias and precision[3]. Sampling precision can be estimated, but bias is difficult to estimate without generally impractical and costly experimental efforts. Contrary to analytical biases, sampling biases are extremely difficult to detect because of material segregation. A valid Quality Control program is required to address Incremental Delimitation Error (IDE), Increment Extraction Error (IEE), Increment Preparation Error (IPE) and Increment Weighing Error (IWE)[4].

The open pit mining industry for various operational and costs constraints has commonly adopted sampling of conventional rotary percussion air blast (RAB) drilling chips that are collected around the drill hole as a source of samples. The data is used to generate short-term models for mine planning and ore control even though this technique does potentially compromise the representativity of the samples collected and submitted for analysis.

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This flawed data potentially compromises pit grade control operations and potential errors in waste versus economic ore designation and extraction.

The present investigation is an evaluation of the precision of samples collected from rotary percussion drilling chips generated and exhausted from the hole and accumulated around the drill. A template of forty (40) independent increments called the "reference template" were collected from the cone of the exhausted material are then compared with twelve (12) different possible sampling patterns/templates. Distribution of drilling chips in the cone does not follow a systematic pattern and is influenced by various factors including geology, drill rig orientation, water table interaction and overall recovery of the drilling chips. The bias of this sampling method was evaluated by comparison of the blast hole sampling data with twinned conventional diamond drill hole core samples which considers the Increment Delimitation Error (IDE) and Increment Extraction Error (IEE) sampling errors.

GEOLOGY OF THE ANTAPACCAY COPPER-GOLD-SILVER DEPOSIT

The Antapaccay mine is 9.4 kilometers southwest from the Tintaya mine site and is a copper-gold-silver porphyry-skarn type ore deposit hosted within the Andahuaylas-Yauri Cupriferous Belt of the Peruvian Andes[5]. It forms part of the Tintaya district which is a Cretaceous limestone/calcareous and siltstone dominated sedimentary series with various intrusive monzonitic plutons. The Antapaccay mine copper mineralization averages 0.52% copper and is hosted predominantly within the monzonite-diorite intrusive associated with finely disseminated chalcopyrite, bornite and chalcocite with only minor quantities of sulphide veinlets. There are some quartz veinlets and stockwork zones commonly associated with higher copper/gold grade and coarser sulphides species as well as irregular contact skarns and mineralized stockworks hosted within the sedimentary units.

The importance of the size distribution, density and the liberation characteristics of the copper species are critical not only for Fundamental Error (FSE), but also for the impact of the economic controls as a result of mineral segregation and/or preconcentration during the sampling of the blast hole drilling chips. The copper sulphide species being potentially rejected or concentrated while the blast holes are drilled due to density/size segregation as well as hole erosion thus potentially resulting in biased samples being collected for the grade control operations

ROTARY BLAST HOLE DRILLING AND MANUAL SAMPLING OPERATIONS.

For this present review, fifteen (15) blast holes were drilled using two (2) tracked mobile rotary percussion air blast drill machines (RAB) using a 12 ¼ inch diameter tricone bit operating at an air pressure of 60 pounds per square inch (PSI). Typically, the generated drilling chips collected around the drill hole are 95% less than 10 millimetres and P50 of 2 millimetres.

The drill hole spacing and drilling procedures were as per the mine's present standard blast hole pattern and internal quality control measures. This investigation was to simulate typical operational variability in blast hole drilling conditions with regards copper grades, mineralization variability and style as well as ground water content and its interaction with the drill units. The present rotary percussion blast hole sampling of the mining bench is divided into two steps:

- Rotary percussion drilling of the designated bench to a depth of fifteen (15) meters. This generates approximately three (3) metric tons of drill chips per hole that are distributed in a cone shape around the blast hole and drill string.
- Manual subsampling of the drill chips from each individual blast hole that are sent to the onsite laboratory for geological mapping and chemical analysis that is used for operational grade control management.

The percussion drilling and subsequent sampling of the generated drill chips is considered to generate various systematic sampling errors including bench delimitation with an over drilling/erosion, sample recovery errors associated with loss of material into fractures as well as material losses during the extraction of the drill chips by ground water interaction and air blown dust/fines losses.

The loss of material is inherent in the rotary percussion drilling processes and sample collection procedures and any operational improvements are limited to the improved sampling of the material exhausted and deposited around the blast hole. It is probable that the material sampled sample does not represent the material from the blast hole profile thus providing operational challenges in using this data for ongoing grade control operations and waste/ore designation.

The large mass of the percussion drill chips, variable cone shape as well as the extremely heterogeneous distribution of the copper content within the cone of material due to segregation are all challenging issues. The task is to design an effective subsampling protocol to provide unbiased data for operational grade control and metal reconciliation with the existing block model. In addition, due to operational and blasting production constraints there is limited time for extensive manual sampling or field division processes to take larger and/ or additional samples.

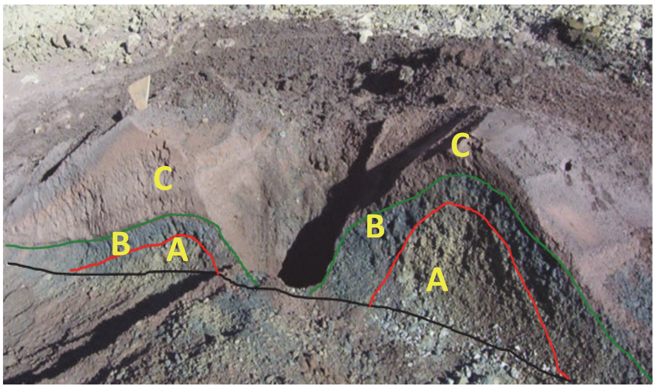


Figure 1. Cross-section example of a typical blast hole drill chip cone. The distribution of drill chips is highly heterogenous both horizontally and vertically relative to the blast hole.

FORTY (40) INCREMENT REFERENCE TEMPLATE FOR EVALUATING PERCUSSION DRILLING SAMPLING PRECISION

The investigation included a forty (40) increment sampling template distributed radially over the percussion drilling chips cone to consider the heterogeneity of metal content, variable shape of the cone and effect of water content. The objective of the template is to collect multiple increments to provide better understanding of the distribution, range and average metal values allocated for the blast hole and is identified as the “Reference Template” (Figure 2 and 3). For this initial review, only the total copper content reported in percentage (%) is considered.

Each increment is collected manually using an 80-millimetre diameter, electric powered, hand-held auger unit inserted perpendicular to the slope of the cone (Figure 4) to generate a sample of approximately three (3) kilograms each. The individual samples are dried, crushed to less than three (3) millimetre and divided using a rotary sample divider to obtain approximately 500 grams of sample. The samples are pulverised/reduced using an Essa® LM2 single disk type mill to a nominal top size of 106 micron.

The reduced samples are homogenised, divided and assayed individually using the mine’s site laboratory routine internal procedures consisting of a four-acid digestion and Atomic Absorption Spectroscopy (AAS) measurement with standard quality control procedures, including appropriate internal and external reference materials.

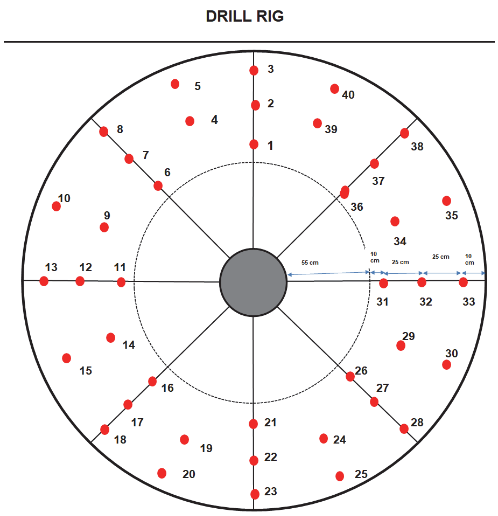


Figure 2. Forty (40) increment sampling "Reference Template "BH100" (red dot sampling points). First increment is collected perpendicular to the drilling rig.

Figure 3. Reference Template sampling points over the blast hole cone

The analysis of the individual forty (40) increments provides the characterisation of the copper grade distribution within the percussion drilling chip cone. Based on this information it is possible to design the alternative sampling templates and calculate their precision comparing to this Reference Template, such as those provided in Appendix 1.

Figure 4. 80-millimeter diameter electric powered, hand-held auger collecting samples perpendicular to the slope of the cone

Figure 5. Fabricated sectional metal frame used for the investigation to collect a complete profile through the cone of drilling chips

In addition to manual sampling with the hand-held auger device, sampling with a sectional metal frame was considered as another possible sub-sampling technique (Figure 5). After forty (40) increments samples are collected, a channel is dug next to the sampling profile and a fabricated sectional steel sampling frame is inserted from the top to bottom of the exposed section of the cone see Figure 5.

The sectional metal frame considers the radial shape to the center of the hole and at eight (8) degree of aperture. This has a minimum aperture of four (4) centimeters near the blast hole and is 120 centimeters in length. However, due to the large mass of each sample (>30 kilograms) the use of the metal sectorial frame is only considered as an evaluation procedure and is not a practical procedure for routine sampling and evaluation.

ANALYSIS OF RESULTS

The copper content in the forty (40) samples collected individually from the blast hole cone were used to contour the obtained copper grade distribution (Figure 6 and 7) over the cone profile. The contour plot in example BH01 the copper content was observed to be enriched in the area opposite to position of the drill rig and contains up to 0.70% copper with a range between 0.20% copper and a maximum of 0.76% (average for hole is 0.35% copper).

The focused concentration of the copper content is striking, suggesting that the deposition of drilling chips is by sections and/or an enrichment due to the effect of density segregation of the particles by the drill flushing air.

Another example (BH06) demonstrated a spiral shaped copper distribution located in the southeast quadrant of the cone with a content of 0.70% copper and reaching the outer southwest quadrant with an enriched content of 2.52% copper. The copper grades demonstrated a large variability between 0.48% to 2.52% copper between the forty increments. (Average for this blast hole is 0.89% copper).

The distribution indicates high variability and with the copper content commonly concentrated /enriched in specific zones of the percussion drilling chip cone.

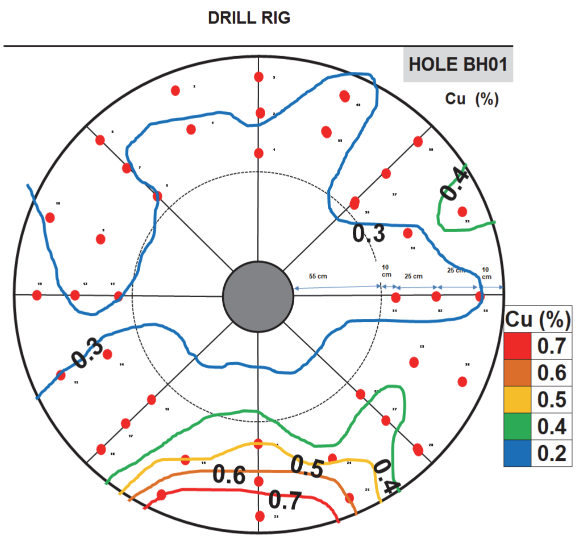


Figure 6. Copper content of blast hole BH01 showing copper enrichment in one specific area of the southern part of the cone closest to the drilling machine

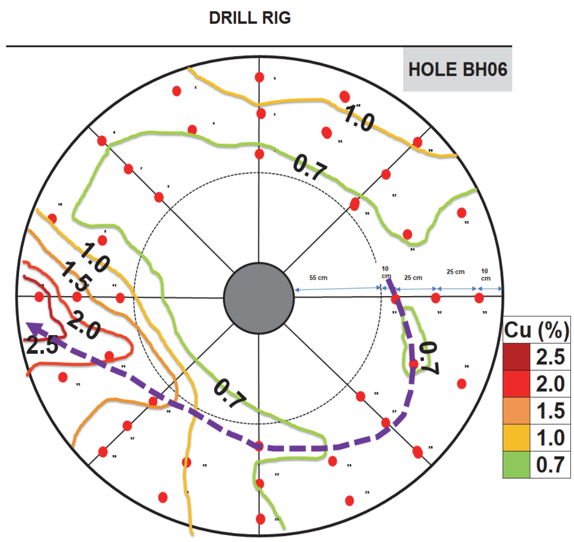


Figure 7. Copper contour of blast hole BH06 showing spiral distribution of copper enrichment

The observed accumulation/ enrichment of copper content in certain sectors of the drill chip cone is attributed to:

- Non-uniform horizontal deposition of chips during the drilling possibly as a function of airflow out of the hole and interaction with the drill machine orientation and possibly prevailing wind direction.
- Effects of air flow channeling by the canvas panels around the drill string installed by drill operators to reduce dust losses/generation resulting in an unequal air flow around the hole orifice.
- Variability in geological units with variable copper mineral content in the blast hole profile due to erosion/over sampling of lithologies.
- Variable operator techniques and time pressure to complete the operations resulting in variable drilling rates.
- Loss of lower density/fine gangue minerals by interaction with air/water flows including air losses into fractures.

The irregular heterogeneity and segregation of drilling chips within and around the cone is demonstrated in the vertical and horizontal plane of the cone producing challenges to collect representative samples of the blast hole profile. Applying the sampling methodology of multiple independent increments in the cone of drilling chips is critical and fundamental to find the appropriate sampling tool or template for routine operations. This will ensure that the percussion drilling blast hole sampling can be used for operational grade control and geological reconciliation.

Figure 8. Material around the rotary percussion drilling cone of blast hole (BH01). Note the material size segregation

Figure 9. Material around rotary percussion drilling cone of blast hole (BH06) (looking towards drill rig). Note the irregular shape of drill chip cone.

In addition, this type of review provides information on the other variables of interest including granulometry of the generated chips, weight of samples and shape of the cone (Figure 8 and 9). These variables can be plotted on a contour map to visualize the distribution of the elements or variable of interest in the material cone. Since these samples are independents and it is then possible to compare the "Reference Template" versus other proposed operational sampling templates. Considering that this reference data provides the ability to define fit-for purpose sampling plan for routine operations.

SIMULATION RESULTS OF REFERENCE TEMPLATE VERSUS OTHER POSSIBLE SAMPLING TEMPLATES.

Using the forty (40) increment template (Reference Template) copper grades it is possible to calculate the copper grade of twelve (12) other possible sampling templates (T1 to T12 - Appendix 1). These possible templates range from 8 to 24 increments and weigh between 6 to 50 kilograms.

In order to select the most appropriate sampling template for both operational and precision requirements, the copper average grade of the Reference Template is compared with each of the twelve (12) possible template's calculated average copper grade (Table 1). Selecting the template that has less than <5% of precision or dispersion versus the Reference Template (Table 2 and Figure 10).

Table 1 - Summary of each possible sampling template (T1-T12) calculated total copper grade and Reference Template (RT) for each blast hole.

Template	ID	Cu (%) T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	RT*
	No increments	8	8	8	8	12	12	12	12	16	16	24	24	40
Blast Hole No.	BH01	0.383	0.312	0.367	0.368	0.419	0.307	0.348	0.353	0.346	0.367	0.356	0.351	0.349
	BH02	0.406	0.433	0.418	0.440	0.416	0.432	0.431	0.417	0.418	0.430	0.424	0.424	0.423
	BH03	0.445	0.436	0.462	0.503	0.489	0.474	0.564	0.448	0.441	0.482	0.482	0.502	0.476
	BH04	0.800	0.688	0.846	0.719	0.812	0.680	0.702	0.834	0.753	0.778	0.756	0.763	0.750
	BH05	0.769	0.838	0.721	0.843	0.790	0.836	0.864	0.730	0.805	0.780	0.814	0.798	0.815
	BH06	0.885	0.930	0.614	1.175	0.806	0.977	1.151	0.647	0.906	0.909	0.891	0.911	0.887
	BH07	0.316	0.306	0.338	0.338	0.344	0.322	0.333	0.313	0.345	0.322	0.336	0.323	0.337
	BH08	0.435	0.434	0.447	0.477	0.444	0.440	0.452	0.439	0.435	0.463	0.442	0.446	0.450
	BH09	1.171	1.064	1.113	1.096	1.170	1.081	1.124	1.097	1.123	1.105	1.129	1.111	1.119
	BH10	0.478	0.518	0.532	0.518	0.496	0.530	0.519	0.533	0.499	0.525	0.515	0.525	0.509
	BH11	0.178	0.230	0.183	0.247	0.187	0.226	0.238	0.187	0.202	0.212	0.206	0.210	0.212
	BH12	0.425	0.385	0.371	0.389	0.420	0.399	0.400	0.400	0.407	0.380	0.411	0.400	0.394
	BH13	0.337	0.310	0.306	0.296	0.341	0.303	0.300	0.314	0.323	0.301	0.322	0.306	0.313
	BH14	1.082	1.169	1.042	1.090	1.116	1.165	1.108	1.108	1.122	1.068	1.141	1.108	1.121
	BH15	0.830	0.926	0.814	0.945	0.825	0.925	0.977	0.801	0.879	0.882	0.880	0.894	0.879

RT*= Reference template

Table 2. Calculated Relative Difference of the possible sampling templates versus the Reference Template for each blast hole**.**

Template	ID	Relative Difference Percentage of sampling template versus reference template (%) T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
	No increments	8	8	8	8	12	12	12	12	16	16	24	24
Blast Hole No.	BH01	9.2	-11.2	5.0	5.2	18.1	-12.8	-0.3	1.0	-0.9	5.1	2.0	0.4
	BH02	-4.1	2.4	-1.0	4.1	-1.5	2.3	1.9	-1.4	-1.1	1.7	0.3	0.3
	BH03	-6.8	-8.7	-3.0	5.6	2.7	-0.4	17.0	-6.1	-7.6	1.3	1.2	5.2
	BH04	6.4	-8.6	12.0	-4.3	7.9	-9.9	-6.7	10.6	0.3	3.6	0.8	1.6
	BH05	-5.7	2.8	-12.2	3.4	-3.1	2.6	5.9	-10.9	-1.2	-4.3	-0.1	-2.1
	BH06	-0.1	4.8	-36.4	28.0	-9.6	9.7	26.0	-31.2	2.2	2.5	0.4	2.7
	BH07	-6.6	-9.7	0.3	0.3	2.0	-4.5	-1.4	-7.5	2.4	-4.6	-0.5	-4.3
	BH08	-3.3	-3.5	-0.6	5.9	-1.3	-2.2	0.6	-2.4	-3.4	2.9	-1.7	-0.9
	BH09	4.5	-5.0	-0.5	-2.1	4.5	-3.4	0.4	-2.0	0.3	-1.3	0.9	-0.8
	BH10	-6.4	1.7	4.5	1.8	-2.6	4.0	1.8	4.5	-1.9	3.1	1.1	3.1
	BH11	-17.3	8.1	-14.6	15.0	-12.5	6.1	11.7	-12.8	-4.9	-0.1	-2.9	-0.8
	BH12	7.4	-2.4	-6.2	-1.4	6.4	1.1	1.5	1.5	3.1	-3.6	4.1	1.5
	BH13	7.3	-1.1	-2.3	-5.6	8.3	-3.4	-4.4	0.2	3.1	-4.1	2.8	-2.4
	BH14	-3.5	4.2	-7.2	-2.8	-0.5	3.9	-1.2	-1.1	0.2	-4.8	1.8	-1.1
	BH15	-5.8	5.2	-7.7	7.2	-6.3	5.1	10.6	-9.3	0.1	0.3	0.1	1.7

Dispersion as a relative difference of the twelve (12) individual sampling templates versus the reference template copper values to measure the degree of precision for each calculated sampling template.

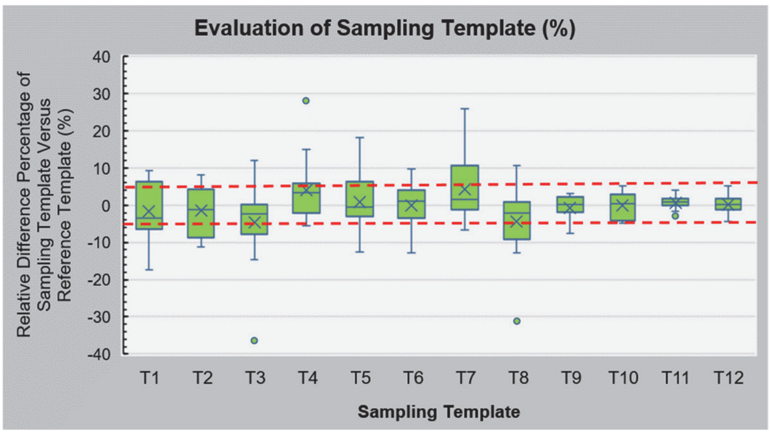


Figure 10. Precision chart of each individual sampling template versus the Reference Template.

Comparisons of the calculated twelve (12) sampling templates versus the Reference Template indicate that the templates T9 and T10 (Appendix 1) have lowest calculated precision < 5% (Figure 10). These results are supported by the total sample weight in a practical range of 15 to 30 kilograms that can be reduced to a subsample of 6 to 10 kilograms for additional sample preparation and analysis (Table 3). Both of these sampling templates (T9 and T10) were also tested for reproducibility and can be considered original and field duplicates.

Table 3. Summary of calculated sample weight (kilograms) of each possible sampling template (T1-T-12) for each blast hole

		Sample weight of each sampling template (kg)											
Template	ID	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
	No increments	8	8	8	8	12	12	12	12	16	16	24	24
Blast Hole No.	BH01	9	9	11	7	12	16	13	17	18	18	28	29
	BH02	13	10	11	12	18	17	19	18	23	22	36	36
	BH03	7	5	5	5	10	9	9	10	12	10	19	19
	BH04	12	9	10	11	19	14	18	15	20	21	33	33
	BH05	9	10	11	10	15	16	17	16	19	21	31	33
	BH06	18	16	15	17	26	26	27	25	34	32	52	52
	BH07	7	11	11	11	21	13	18	16	21	21	33	34
	BH08	14	9	11	13	21	15	19	17	23	23	36	36
	BH09	16	13	14	14	25	22	24	23	29	28	47	46
	BH10	12	14	12	14	19	23	22	21	26	26	41	43
	BH11	10	8	10	8	15	15	13	15	18	18	30	28
	BH12	11	9	9	11	16	12	16	14	19	20	28	30
	BH13	11	11	9	11	18	16	18	14	22	20	34	32
	BH14	7	6	6	7	10	11	11	11	13	13	21	22
	BH15	11	12	11	12	15	19	18	16	23	23	34	35
	Min	7	5	5	5	10	9	9	10	12	10	19	19
	Max	18	16	15	17	26	26	27	25	34	32	52	52

EVALUATION OF SAMPLING BIAS - DIAMOND DRILL CORE SAMPLES VERSUS PERCUSSION DRILLING BLAST HOLE SAMPLES.

Fifteen (15) HQ (63.5mm) sized conventional diamond drill cores were drilled at no further than 0.7 meters away from the percussion drilling blast holes to a depth fifteen (15) meters to provide a direct comparison against the individual blast holes assay results. The diamond drill core recoveries were logged to be 98-100% across the sample widths.

Investigating the sampling bias and the changing transient nature requires a reference sample that is correct, and not affected by an Increment Delimitation Error (IDE) nor an Increment Extraction Error (IEE). As part of the extraction error, the possible “plucking effect” of copper sulphides should be mentioned as potential for low recovery of sulphides species in diamond drill core samples. This possible effect on typical Antapaccay ore has not been reported by the geologists during logging of the diamond drill cores and is considered to be minimal due to the finely disseminated sulphides as well as the compact and unweathered intrusive nature of the orebody.

DIAMOND BORE CORE SAMPLE PREPARATION PROTOCOL

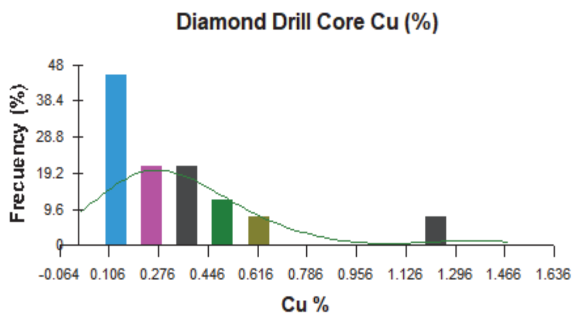
The bore core samples preparation protocol is as follows:

- As per standard procedure the diamond core is divided into 2.5 meters intervals for sampling and chemical analysis. Each individual diamond drill core provides seven (7) separate assay samples that are averaged for the entire profile.

- The diamond drill core is split 50% using a rotary diamond saw into A and B samples following geologist instructions after logging.
- Complete crushing/reduction of the A sample core samples to less than three (3) millimeters using a conventional jaw crusher and divided using a rotary sample divider to approximately 600 grams of sample
- The samples are pulverized/reduced using an Essa® LM2 single disk type mill to a nominal top size of 106 micron.
- Pulverized samples are divided via incremental division for chemical and repeat/reserve purposes.
- The reduced samples are homogenized, divided and assayed individually using the mine's site laboratory routine internal procedures consisting of a four-acid digestion and Atomic Absorption Spectroscopy (AAS) measurement with standard quality control procedures, including appropriate internal and external reference materials

DIAMOND DRILL CORE SAMPLES DATA ANALYSIS

The mine geologists consider 2.5 meters sampling interval appropriate for the finely disseminated copper mineralization. This investigation involved fifteen (15) diamond drill holes and subsequently 115 samples for copper analysis. The histogram of the copper demonstrated a significant skewness to the grade data (Figure 11).



Count	115
Average copper %	0.53
Standard deviation	0.479
Coeff. of variation	90.10%
Minimum value	0.06
Maximum value	3.16
Range	3.10
Standard skewness	9.3
Standard kurtosis	2.5

Figure 11. Plot of the diamond drill core 2.5-meter sample interval copper results for all data (n=115).

The average copper grade of each diamond drill hole is calculated as the weighted average copper grade from the length of bore core samples. The sampling bias evaluation is performed by comparing the data of percussion blast hole drilling template No. T9, the sectional frame sample and the diamond bore core data for each fifteen (15) sampling locations. As the samples collected from the rotary percusion drill chips are considered potentially to be biased the sampling template takes into acount only the precision.

In summary, the bias of blast hole drill chips sampling (Reference Template) versus the diamond drill core is 26.7 % as a median, because the distribution is not normally distributed (Table 5).

Even though the bias of the sectional metal frame sampling method does improve the sampling relative to the bore core assay data (relative difference 12% versus 26.7%). It is however not practical to perform this sampling technique on a routine basis due to the large sample mass generated and significant time and resources required to collect the samples.

TABLE 4. Summary of diamond bore core, percusion blast hole chip reference template, template No. T9 and sectional frame total copper (TCu %) results for the fifteen (15) sampling positions.

Hole No.	Diamond Drill Core TCu %	Reference Template TCu %	T9 TCu %	Sectional frame A TCu %	Sectional frame B TCu %	Sectional frame (A+B) TCu %
1	0.336	0.349	0.346	0.314	0.309	0.311
2	0.233	0.423	0.418	0.428	0.516	0.477
3	0.277	0.476	0.441	0.335	0.407	0.367
4	1.087	0.750	0.750	0.730	0.955	0.802
5	0.765	0.815	0.815	0.622	0.656	0.622
6	1.115	0.887	0.887	1.024	1.335	1.252
7	0.187	0.337	0.337	0.358	0.202	0.234
8	0.445	0.450	0.435	0.445	0.377	0.395
9	0.927	1.119	1.123	1.098	1.118	1.107
10	0.365	0.509	0.509	0.376	0.378	0.377
11	0.163	0.212	0.212	0.133	0.227	0.193
12	0.222	0.394	0.407	0.297	0.342	0.335
13	0.247	0.313	0.323	0.255	0.339	0.255
14	0.868	1.121	1.122	1.125	1.154	1.125
15	0.855	0.879	0.879	0.827	0.882	0.827
Average	**0.517**	**0.583**	**0.580**	**0.539**	**0.594**	**0.561**

TABLE 5. Summary of calculated sampling "bias" for blast hole chips, reference template, T9 template and sectional frame versus diamond drill core samples using the average copper content

Hole No.	Reference Template vs Diamond Drill Core (%)	T9 vs Diamond Drill Core (%)	Sectional frame (A) vs Diamond Drill Core (%)	Sectional frame (B) vs Diamond Drill Core (%)	Sectional frame (A+B) vs Diamond Drill Core (%)
1	4.0	3.1	-6.5	-8.0	-7.3
2	81.3	79.2	83.6	121.3	104.7
3	72.1	59.4	21.1	47.1	32.5
4	-30.9	-30.9	-32.8	-12.1	-26.2
5	6.5	6.5	-18.8	-14.2	-18.8
6	-20.5	-20.5	-8.2	19.7	12.2
7	80.1	80.1	91.1	7.8	25.1
8	1.0	-2.4	-0.1	-15.4	-11.4
9	20.8	21.2	18.5	20.7	19.5
10	39.6	39.6	3.1	3.7	3.5
11	30.4	30.4	-18.3	39.5	18.6
12	77.9	83.5	34.0	54.3	51.0
13	26.7	30.7	3.1	37.0	3.1
14	29.2	29.4	29.7	33.0	29.7
15	2.8	2.9	-3.3	3.2	-3.3
Median	**26.7**	**29.4**	**3.1**	**19.7**	**12.2**

DISCUSSION

The manual sampling of rotary percussion drill blast hole drilling chips has several sampling errors potentially compromising its use as a grade control tool. These inherent errors are due to variable drilling chip recovery, loss of the fine fraction as dust or washed out by water, over sampling outside the drill hole dimensions and irregular segregation of density and size fractions. However, there is still an operational requirement to utilise these blast hole samples for grade control, so it is imperative to try to obtain acceptable and unbiased data as well as to manage cost constraints and production blast cycle times.

The tested forty (40) increment sampling template allows the identification of the distribution of the copper grades within the cone of drilling chips. This data allows the design of an appropriate sampling template with the highest practical precision and manageable mass of samples. The versatility of this template permits the simulation of different sampling templates by reducing the number of increments and weight of samples for a required sampling precision.

The contouring of the copper grades from the individual increments demonstrated a substantial irregular and unpredictable distribution of copper concentration within the blast hole chips which are at times is significantly higher (>10 times) than the average copper grade of the blast hole. This extreme variability in copper distribution cannot be identified without this tool and demonstrates the complexity and susceptibility to bias and poor precision if the copper grade distribution is not fully appreciated. The unpredictable distribution of the copper grade within the cone of blast hole chips indicates that the most appropriate increment sampling template is a cross-shaped pattern that collects samples radially in four directions (the first increment collected perpendicular to the drill rig position - see Figure 2). In addition, this template can also be rotated 45 degrees for duplicate sampling and to verify that the relative reproducibility difference is less than 5%.

Collecting incorrect or biased samples for analysis has a significant impact on grade control, metal reconciliation and incorrect classification of ore and waste. Other sampling procedures including sampling with a sectorial metal frame are not precise, reproducible and creates significant uncertainty in selecting the samples. The diamond drill cores are considered the best available reference samples to verify the inherent sampling bias generated by various other blast hole chip sampling methods. As indicated in the literature, bias is not a constant variable, therefore, the test results are the best estimator for the variables considered in this work.

GOOD OPERATING PRACTICES FOR BLAST HOLE DRILLING AND CONE FORMING

Rotary percussion blast hole drilling with manual sampling of the drilling chips based on the field observations, analytical results and observed copper grade distributions, the following improvements are suggested:

- Maintain the vertical orientation of the drill rig to avoid circular eccentric movements that affect the recovery and size/density segregation of chips removed by the compressed air.
- Keep the skirts of the bore hole machines in good condition - they should be square, uniform and with the canvas covers to reduce the loss of fines and to ensure a circular and more uniform formation of the cone of drill chips
- Drain and dewater the benches before drilling as water ingress is the most important factor impacting segregation and poor recovery of drilling chips. The finer particles are washed out by water in benches and increases the size segregation and concentration of sulphide species.

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Appendix 1- Sampling templates for simulation and determine the best sampling templates with <5%relative difference to the reference 40 position template.