CAPPONI, L., PERONI, R.D.L., GRASSO, C.B. and FONTES, S.B. Sampling protocol review of a phosphate ore mine to improve short term mine planning. *Fourth World Conference on Sampling & Blending,* The Southern African Institute of Mining and Metallurgy, 2009.

Sampling protocol review of a phosphate ore mine to improve short term mine planning

L. CAPPONI*, R.D.L. PERONI†, C. B. GRASSO* and S.B. FONTES*
**Fosfertil S.A. and †Federal University of Rio Grande do Sul*

At Tapira Mine (Tapira/MG/ Brazil), the largest phosphate concentrate producer in Brazil, the mining is fully mechanized and carried out using open pit mining.

This work presents a review of the sampling protocol used for short term mine planning at different stages. Sampling is carried out in two steps. Firstly, diamond drill cores are sampled at $50 \times 50 \times 5$ metre pattern.

Fosfertil analyses grades of P_2O_5, Fe_2O_3, CaO, MgO, SiO_2 and TiO_2 plus geological logging. This information feeds the long term block model. Secondly, drill cuttings are collected at the mining faces released for blasting.

The drilling pattern is staggered and when blasting is not necessary, a drill hole is made centered in the block area ($25 \times 25 \times 5$ m). The primary samples have mass approximately 60 kg and the same chemical parameters are analysed. Metallurgical and mass recovery tests are performed as well. These samples are used to build the short term block model. At the final stage, the short term mine planning model is used to build a stockpile blending model which is simulated using a spreadsheet to match the goals established by the process plant.

Introduction

The difficulty of estimating grades for short term mine planning for the complex geology of phosphate ore deposits in the Brazilian central area, has led to a diagnosis for future review of the sampling protocol applied at Tapira Mine in order to check if sampling results are consistent and within an acceptable level of error. This review used 154 samples from diamond drilling used and 181 samples from blast hole cuttings and their duplicates. The sampling error from the differences was compared to the error defined by sampling theory (Gy, 1982). Gy's sampling theory distinguishes seven basic errors:

- • Fundamental error, resulting from the heterogeneity of material and which cannot be eliminated
- Grouping and segregation error, resulting from the heterogeneity of sampled material, relates the heterogeneity and grouping from the samples by means of segregation and grouping factors, respectively. The segregation factor can be minimized by sample homogenization. The grouping factor can be minimized by using samples having the smallest particle size possible
- Integration error, resulting from long-term grade variation in the material
- Periodicity error, resulting from periodical variations in grade
- Delimitation error, resulting from incorrect delimitation of the form and volume of the sample
- Extraction error, resulting from an incorrect extraction. An extraction would be correct if all particles with centers of gravity within the increment delimitation limits were extracted
- Preparation error, resulting from the sum of errors caused by contamination, losses, chemical or physical alteration and human errors. By managing these sampling errors it is possible to minimize biases, thereby achieving the precision and accuracy requested by mine planning. This means building a model that specifies which blocks will be mined, sent to the process pile or to the waste dump.

Geological and mineralogical context

Tapira's phosphate deposit is located in an ultrabasic intrusion formed by a sequence of pulses that started with silicate ultrabasic and ended with carbonate and hydrothermal events. This petrologic evolution over time created a petrographical zonation with ultramaphics filling mainly the borders of the structure, while the late phases concentrated within the core zone. Intense weathering was the strongest agent responsible for the phosphate concentrations. In the weathered zone, we can notice a vertical typological and chemical zonation. From a typological point of view, this gradation is continuous from the top surface towards the base. It can be grouped into four zones, from top down, according Figure 1.

- Overburden containing silt-clay material, barren with a thickness from 30 to 55 m
- Very weathered rock with high titanium concentration, with thickness varying from 25 to 35 m
- Weathered rock with the highest phosphate concentration and with a thickness varying from 25 to 30 m
- Bed rock.

From a chemical perspective, the weathering washed out the mobile elements such as calcium, magnesium, potash and silica, concentrating elements as phosphorous, titanium, niobium and rare earths plus the contaminants iron and aluminum. In this process, titanium and phosphate suffered

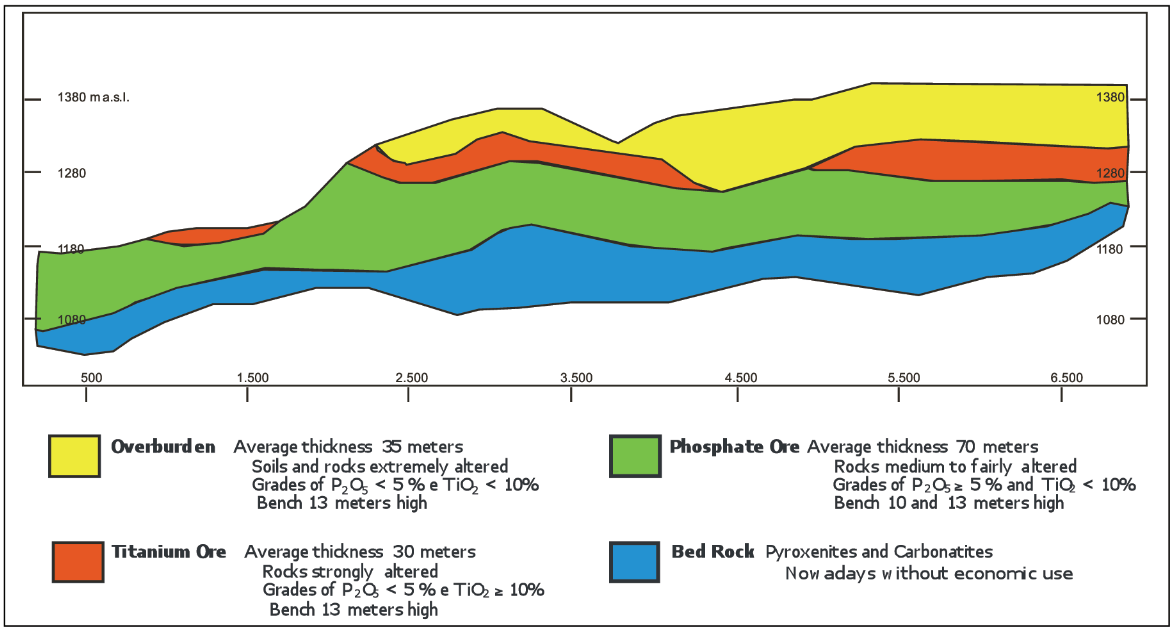


Figure 1. Geological model showing the phosphate and titanium mineralized horizons

vertical segregation as well. Figure 1 can be used as phosphate's geological model and titanium mineralization, showing the grade evolution of TiO_2 and P_2O_5. In this sense, the weathering tended to form two mineral concentrations of economical interest superimposed: one of titanium on top and the phosphate at the bottom zone.

Phosphate concentrate production

At Tapira's mine, concentrate production is about 2 mtpa. The mine works using open pit mining, the cut-off grade is 6% P_2O_5, the average grade is 7.5% P_2O_5 which is concentrated to 34.7 % by processing. The sampling data for mine planning purposes are obtained from a programme of 2 000 m of diamond drill hole and approximately 10 000 m of blast holes per year. This amount of drilling generates more than 2 500 samples are used to build a database for short term mine planning.

Methodology

The sampling process and selection for mine planning purposes can be split in two separate processes, according to Figure 2.

- Sampling with diamond drill hole (DD) – [ϕ = 2.5"]
- Sampling with blast holes (BH) – [ϕ = 3.5"].

The samples collected at the mining faces are defined within pre-established limits (like areas delimited in Figure 3), selected randomly within a block of 50 × 50 × 5 m using diamond drill holes. On the other hand, the blast holes samples are performed on blocks of 25 × 25 × 5 m, a condition determined by the capacity of the mining equipment and the associated ore types.

The two sampling procedures are used to generate two different block models. A long term model, based on the DD samples, gives the general orientation and the areas that will be mined. A short term based model on BH samples is

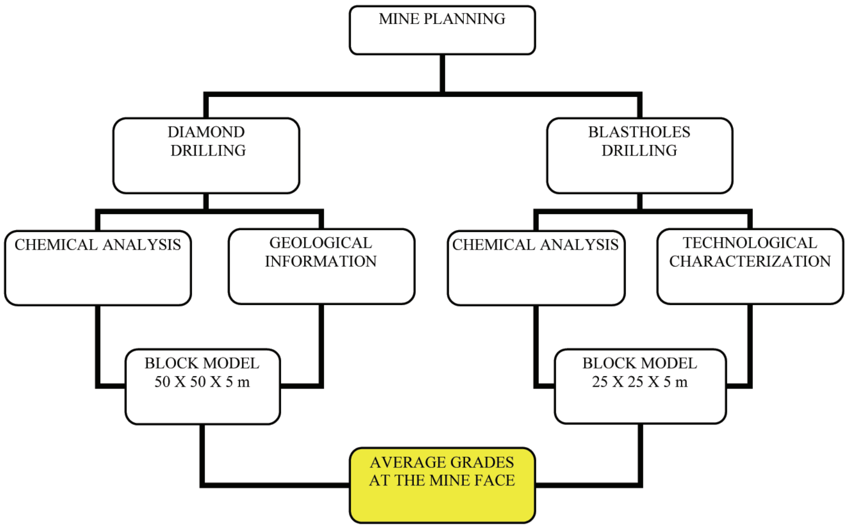
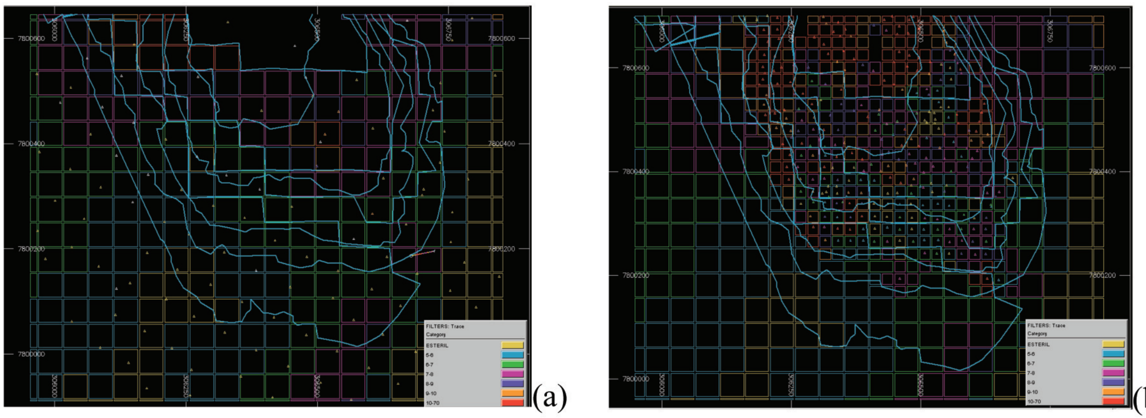
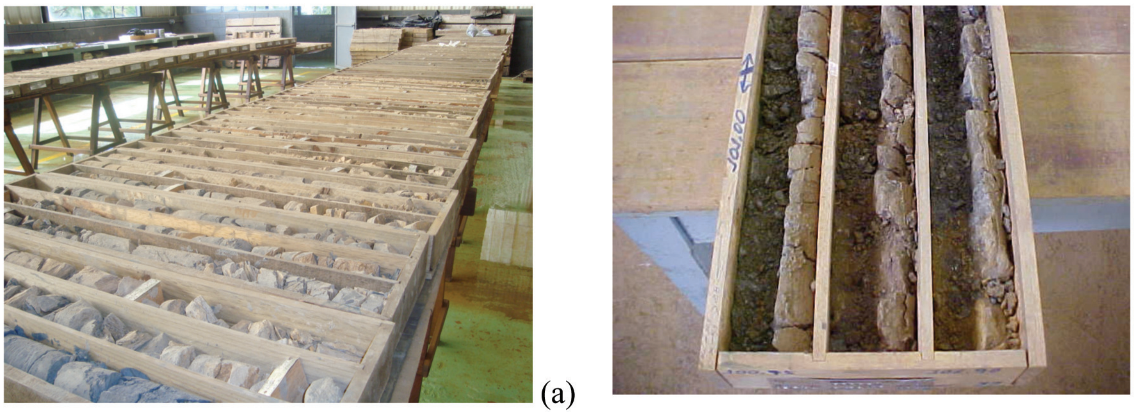


Figure 2. Flowchart of the sampling process at the mine face



(a) (b)

Figure 3. Delimiting the sampling areas at the mine faces. Samples from the DD samples (a) and samples from the BH pattern on 25 × 25 m block model (b)



(a) (b)

Figure 4. Selection and collection of samples taken from the mine face

used for determining the estimated grades of the blocks.

Diamond drill hole (DD) sampling

Based on 2009 mine planning, 154 samples were selected from the DD. From each initial core, a ¼ of it was taken using a scoop along the 5 m length. This sample weighs approximately 30 kg (Figure 5). The samples were prepared and analyzed for P_2O_5 and contaminant elements (Fe_2O_3, SiO_2, TiO_2, MgO and CaO). Figure 4 shows the core boxes from the diamond drill hole with 2.5” diameter. In the right hand picture, one can observe the sample remaining after collecting the original sample and a duplicate of about 30 kg each.

After sample collection, the preparation protocol had the features listed below:

- 30 000 g collected from the drill holes
- 1 000 g taken from the 30,000 after drying, crushing, homogenizing and splitting
- 500 g taken from the 1 000 after pulverizing, homogenizing and splitting
- 30 g taken from 500 g for chemical analysis.

The sampling routine is shown in Figure 5, below. The flowchart presents the stages where there is particle size reduction followed by mass splitting.

The sampling routine was repeated for the original and the duplicate samples. The differences are summarized in the statistical plots. Figure 6 shows a histogram of P2O5 errors calculated from the difference of original sample minus the duplicate sample. The cumulative distribution of differences is shown on Figure 6 (b). The last plot (Figure 6 (c)) shows a scatter plot of the original and duplicate samples.

Blast hole sampling

Based on 2009’s short term mine planning, 181 samples were selected from the drill cuttings. According to Figure 8 the samples were collected manually in the field by shoveling the pile diagonally to get the initial amount of material to be sent to the preparation protocol.

From each blast hole, about 60 kg of initial sample material was collected, followed by the preparation protocol and chemical analysis for the main attributes P_2O_5, Fe_2O_3, SiO_2, TiO_2, MgO e CaO. The preparation protocol follows below.

- 60 000 g collected from the blast holes cuttings
- 30 000 g taken from 60 000 collected from the blast holes (manual sampling with diagonal splitting with shovel)
- 1 000 g taken from the 30 000 g after drying, crushing, homogenizing and splitting
- 500 g taken from the 1 000 g after pulverizing, homogenizing and splitting
- 30 g taken from 500 g for chemical analysis, after splitting.

Again, the procedure was repeated for the original samples and the duplicates. The differences between the two set of samples were calculated, as shown in Figure 9.

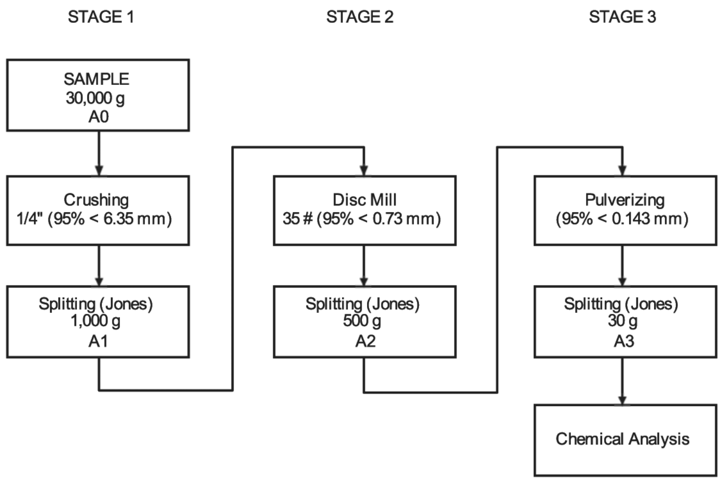


Figure 5. Preparation protocol diamond drill hole (DD) samples

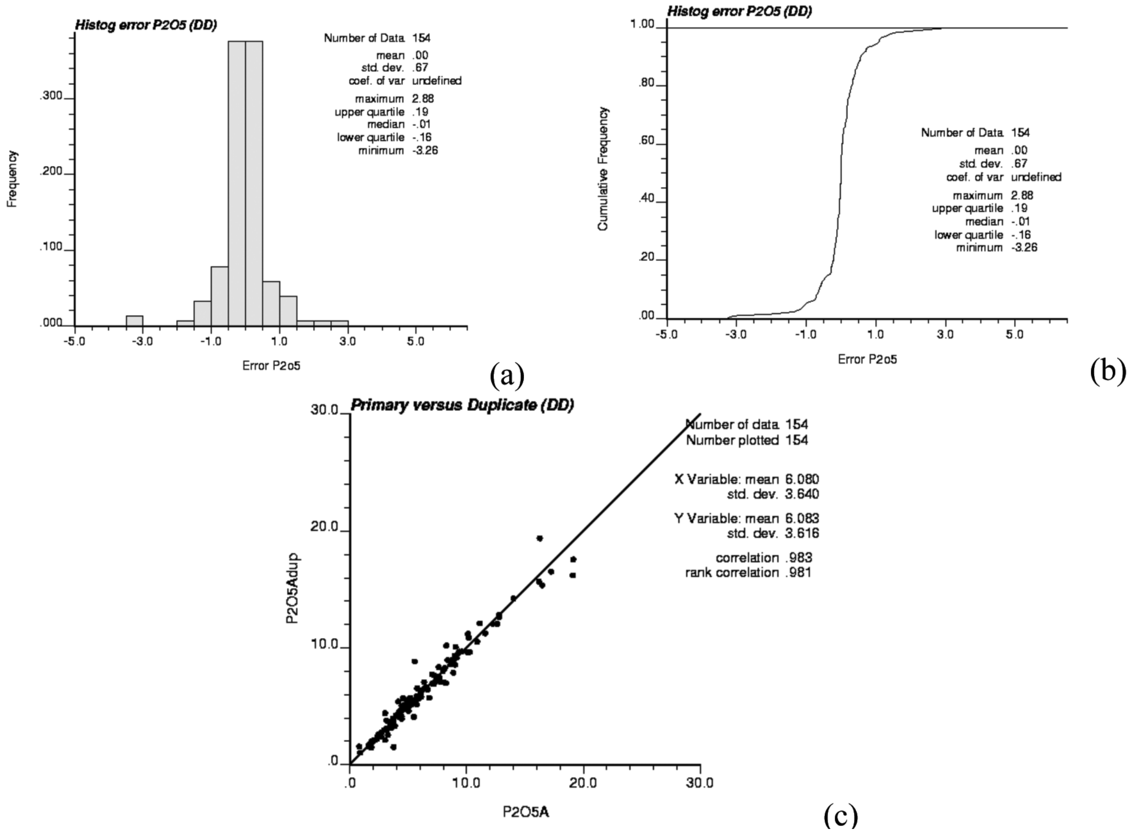


Figure 6. P_2O_5 histogram of the errors for diamond drill holes duplicates (a). P_2O_5 cumulative histogram of errors for diamond drill holes duplicates (b). Correlation between the P_2O_5 primary analyses versus P_2O_5 duplicate samples (c)

Sampling theory and parameters adjustment of Gy's Equation

Fundamental error theory, defined according Gy's formulae, referenced by Grigorieff (2002), is described below:

M_E (g): Sample mass;
M_L (g): Initial mass;
C: Sampling constant;
d (cm): Sample particle top size (d = 95% passing);

The sampling constant C is obtained trough the following equation:

$C = c \cdot l \cdot f \cdot g$

l: liberation factor

Considering l is given by:

$l = (d_{lib}/d')^{0.5}$

d_{lib} (cm): liberation size of particle

f: particle form factor

g: size factor (estimated from the relation of the top size and the under size)

c: mineralogical compound factor

Figure 7. Blast hole drilling at the mine face

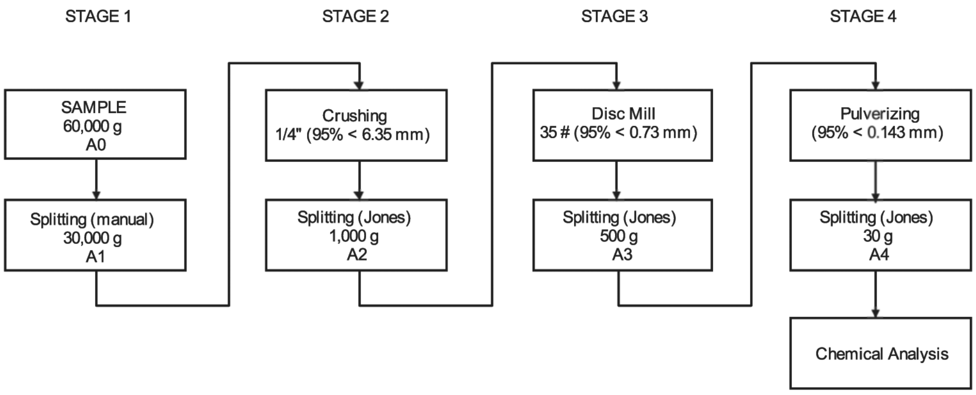


Figure 8. Preparation protocol to the blast hole (BH) samples

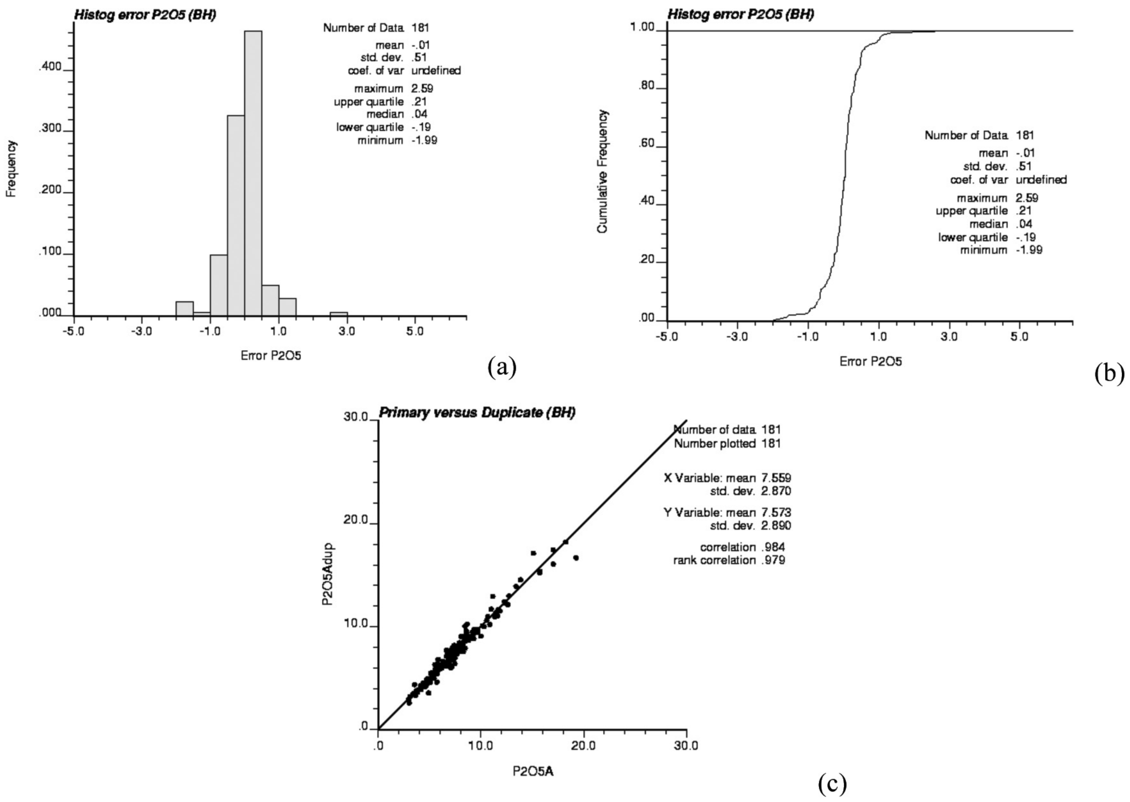


Figure 9. P_2O_5 histogram of errors for blast holes samples (a). P_2O_5 cumulative histogram of errors (b). Relationship between primary P_2O_5 versus duplicate P_2O_5 samples (c)

Considering c is given by:

$c = (1 - a)[(1 - a)\ \rho_1 + a\rho_2]/a$

a: concentration of the considered component
ρ_1 (g/m³): particle density of the critical component
ρ_2 (g/m³): other components particle density

Protocol review according the sampling theory

Based on sampling theory, the fundamental error variance for the protocol used at Tapira's mine was calculated, as shown on Tables III and IV.

Table III indicates the variance of the sampling of error (SE Total), result from the sum of variances (EF), plus the variance of the error of segregation and grouping (ESG) plus variance of the analytical error (EA). The standard deviation of the sampling error is 2.07 x 10-2. To determine the interval of error with 95% confidence, it is necessary to convert the relative standard deviation to absolute, as follows below:

$(S_{E\ Total})$ absolute = $(S_{E\ Total})$ relative * P_2O_5 % grade

Interval = +/- 2 * $(S_{E\ Total})$ absolute = +/- 0.2487%

In this sense, one can consider that the application of sampling theory to the protocol used for the DD samples determines the P_2O_5 grade can be reproduced from the duplicate tests must fall in between the interval described below:

6.0% +/- 0.2487%, or in between 5.75% and 6.25 % of P_2O_5. Considering the average grades for the DD samples.

Analysing the data the same way as the DD protocol, one can verify that the sampling reproducibility, considering only the influence of fundamental error, this would be 7.55% ± 0.2834%. Comparing the results from the two sampling procedures using Gy's theory, against the error produced by the duplicate tests one can check the duplicate test variability against the sampling theory error. The standard deviation from the duplicate tests presented on Figures 6 (a) and 9 (a), represents the absolute error between the duplicate samples. If we divide this value by the average grade of the samples and multiply by 2 to have 95% confidence level we get for the DD duplicate samples:

$$E_{rel} = \frac{E_{abs}}{Grade} = \frac{0.67}{6\%} = 0.11 \Rightarrow 0.11 * 2 = 0.223\ (95\%\ conf.)$$

And for the BH duplicate samples:

$$E_{rel} = \frac{E_{abs}}{Grade} = \frac{0.51}{7.55\%} = 0.068 \Rightarrow 0.068 * 2 = 0.135\ (95\%\ conf.)$$

Table III
Variance of error, calculated based on the DD samples

		EF			ESG	EA
		Stage 1	Stage 2	Stage 3		
M_E (g)	-	1 000	500	30		
M_L (g)	3.E+04	3.E+04	1 000	500		
ρ_1	2.25	2.25	2.25	2.25		
ρ_2	1.70	1.70	1.70	1.70		
a	0.06	0.06	0.06	0.06		
c (g/cm³)	34.73	34.73	34.73	34.73		
d (cm)	2.0	0.635	0.075	0.0143		
d_{lib} (cm)	0.025	0.025	0.025	0.025		
l	0.112	0.198	0.577	1.322		
f	0.50	0.50	0.50	0.50		
g	0.25	0.25	0.25	0.25		
C (g/cm³)	0.4854	0.8615	2.5066	5.7406		
s^2E		**2.13E-04**	**1.06E-06**	**5.26E-07**	**2.14E-04**	**1.75E-07**

Table IV
Variance of error calculated from the protocol from the BH samples

		EF				ESG	EA
		Stage 1	Stage 2	Stage 3	Stage 4		
M_E (g)	-	30 000	1 000	500	30		
M_L (g)	-	6.E+04	30 000	1 000	500		
ρ_1	2.25	2.25	2.25	2.25	2.25		
ρ_2	1.70	1.70	1.70	1.70	1.70		
a	0.076	0.076	0.076	0.076	0.076		
c (g/cm³)	27.04	27.04	27.04	27.04	27.04		
d (cm)	1.0	1.0	0.635	0.073	0.0143		
d_{lib} (cm)	0.025	0.025	0.025	0.025	0.025		
l	0.158	0.158	0.198	0.585	1.322		
f	0.50	0.50	0.50	0.50	0.050		
g	0.25	0.25	0.25	0.25	0.25		
C (g/cm³)	0.5345	0.5345	0.6707	1.9782	4.4696		
s^2E		**8.91E-06**	**1.66E-04**	**7.70E-07**	**4.10E-07**	**1.76E-04**	**1.75E-07**

Conclusion

Based on sampling theory, it was verified that the protocol applied to the DD samples performed a little bit better than the BH samples, even though the number of samples and the interval were not the same but very close.

The study went through the main sources of error. According to Gy's theory, the error occurs always when there is mass reduction. This must be compensated by a particle size reduction as well. In this case study, the original samples and its duplicates presented a range of variation that was quite restrictive.

The sampling protocol seems to be adequate to the problem at hand, for the P_2O_5 grades. Considering P_2O_5 is the main aspect controlling mine planning, the samples produced results within an acceptable range of variation and a small number of samples outside the range determined by the sampling theory. This study could be extended to the other elements if they become relevant to define mine planning strategy and process routes.

It is important to say that some values used at Gy's equation, could be better investigated to make sure the assumptions made at this point are not misleading some results and consequently the conclusion obtained at this stage. Parameters such as form factor (f) and liberation diameter (dlib) were assumed constant and based on fixed assumption made in a few evidences that should be further analysed.

The frequency graphs, the cumulative histograms of error and the correlation plots show that the sampling protocol and the analytical method is unbiased where the average of errors is very close to zero and the variance of errors is small enough to say the procedure is accurate and precise based on these results.

From this study, systematic sampling and duplicates to blast holes to assure the quality of results from this sampling campaign will be implemented as well some biases associated with the sample collection could be mitigated to improve sample quality (e.g. fines lost, subdrilling, coarse segregation, field splitting, etc.).

From the Gy formula, it was observed that the major parcel of error comes from the bigger mass reduction (from 30 kg to 1 kg), hence in this step, if one wants to reduce the ESG error, one should consider reducing the particle size at this stage for both procedures DD and BH.

References

GRIGORIEFF, A. Desenvolvimento de um novo protocolo de amostragem de carvão mineral. Dissertação de mestrado. PPGEM, UFRGS, Porto Alegre, 2002. Pp. 178.

GRIGORIEFF, A., COSTA, J.F.C.L. and KOPPE, J. O problema de amostragem manual na indústria mineral. REM: *Revista Escola de Minas*, 2002. vol 55, no. 3, pp. 229–233, July/Sept. Escola de Minas, Ouro Preto.

GY, P.M. *Sampling of particulate materials theory and practice*. Amsterdam: Elsevier, Second Revised Edition, 1982. pp 431.

Luciano Nunes Capponi

Mining Planning Engineering, Fosfertil S.A.

Graduated in 2000 as Mining Engineer at Federal University of Rio Grande do Sul (UFRGS). Worked as manager production in Monego's Mine, mine of limestone localized in south Brazil. Worked in Pedraccon's Mine as Mining Engineer. Working as an Engineer of Mine Planning and Geology Department at Fosfertil S.A. at a company Chemical Fertilizer in Brazil.

Rodrigo Peroni

Adjunct Professor, Federal University of Rio Grande do Sul

Graduated in 1994 as Mining Engineer at Federal University of Rio Grande do Sul (UFRGS),

After his graduation worked as an independent consultant and managed MINX-Mineração Ltd. a company for resources evaluation, mine planning and mining services in general like blasting and drilling. Finished his Masters degree in 1998 in geostatistics field (UFRGS), Finished his PhD in 2002 in Mine Planning and Resources Assessment (UFRGS), worked as substitute professor at Federal University of Rio Grande do Sul. In 2003 assumed as Chief Engineer of Mine Planning and Geology Department at Rio Paracatu Mineração (RPM) a company prior of Rio Tinto group and then sold to the Kinross Gold Corporation, in 2006 left the RPM to go back to the academics as Adjunct Professor teaching courses like Open Pit Mine Planning and Design, Engineering Geology and Mining Projects besides his research as his specialty as geostatistician and open pit mine planning and applied softwares to geological modeling and mine planning and design.