WCSB7 7th World Conference on Sampling and Blending
10-12 june 2015 Bordeaux, France
Centre de Congrès Cité Mondiale 18 parvis des Chartrons - 33080 Bordeaux

GEOSTATISTICAL COMPARISON BETWEEN BLAST AND DRILL HOLES IN A PORPHYRY COPPER DEPOSIT

(June 2016 version)

Serge Antoine Séguret – Mines-ParisTech, France

CODELCO Produciendo Futuro
Codelco Chili

WCSB7 7th World Conference on Sampling and Blending
10-12 june 2015 Bordeaux, France
Centre de Congrès Cité Mondiale 18 parvis des Chartrons - 33080 Bordeaux

Mines-ParisTech

Good morning everybody.

I am pleased to present you the work entitled

"GEOSTATISTICAL COMPARISON BETWEEN BLAST AND DRILL HOLES IN A PORPHYRY COPPER DEPOSIT ».

This work is supported by the Chilean company Codelco, which produces copper, and the Paris School of Mines where I have worked for over thirty years in the Geostatistical laboratory founded by Georges Matheron at Fontainebleau.

Drill holes, blast holes

Drill holes

- Few
- Long-term planning (month, year, decade)
- Large-scale strategy
- Good quality

Blast holes

- Many
- Short-term planning (day, week,)
- Small-scale selectivity
- Bad quality

2

Typically in open pit mines, geologists, mining engineers, metallurgists, have at their disposal two types of measurements for the grades:

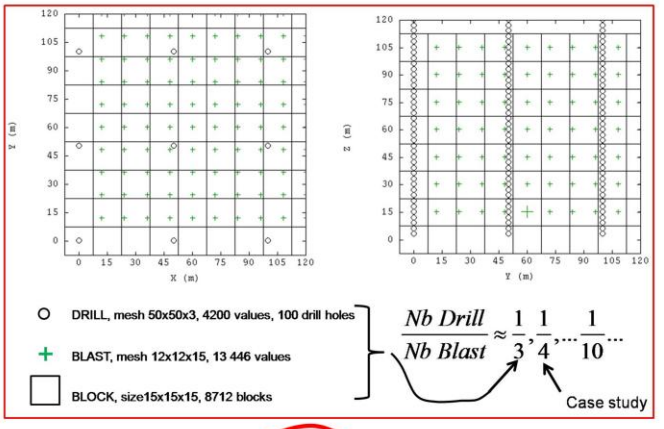
A first type, from drill holes – "diamond drill holes" in our case.

A second type, from the blast holes.

Drill holes, blast holes

Drill holes

- Few
- Long-term planning (month, year, decade)
- Large-scale strategy
- Good quality



Blast holes

- Many
- Short-term planning (day, week,)
- Small-scale selectivity
- Bad quality

3

Because they are much more expensive, the diamond drill holes are less numerous than the blast holes, and it is usual to encounter sampling rates ranging from one over three to one over ten or worse.

Not only the sampling density is involved but also how samples are distributed in space too, as shown on the slide:

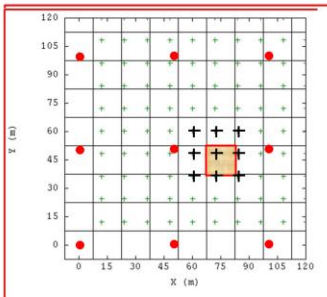
- The circles, representing the drill holes, are widely spaced, see the left horizontal cross-section
- In the same figure, the green crosses, representing the blast holes, are more densely spaced
- Vertically, on the right-hand figure, it is the reverse, with almost continuous drill hole information while the blasts are more widely spaced

These differences make it even more difficult to compare the statistical properties of the two types of measurements, including when calculating directional variograms because statistical inference conditions are not the same

Drill holes, blast holes

Drill holes

- Few
- Long-term planning (month, year, decade)
- Large-scale strategy
- Good quality



Block kriging using: •

Moving average using: +

Blast holes

- Numerous
- Short-term planning (day, week,)
- Small-scale selectivity
- Bad quality

4

Another difference concerns the way the measurements are used.

The long road that leads to the opening of the mine is marked by drilling campaigns, to achieve the block model that will condition the exploitation at large scale as well as for medium- and long-term planning. Typically, kriging and Geostatistics are used to build the model at this stage.

In addition, the blast holes are used for short term planning with no need of Geostatistics, a simple moving average is often used to estimate the block quantity of metal

These separate uses of two types of measurements that are supposed to represent the same thing raise questions about their relationship. In particular, would it not be possible to enrich the short-term estimate, now based only on blast holes, by adding the drill hole measurements?

Drill holes, blast holes

Drill holes

- Few
- Long-term planning (month, year, decade)
- Large-scale strategy
- Good quality

?

Blast holes

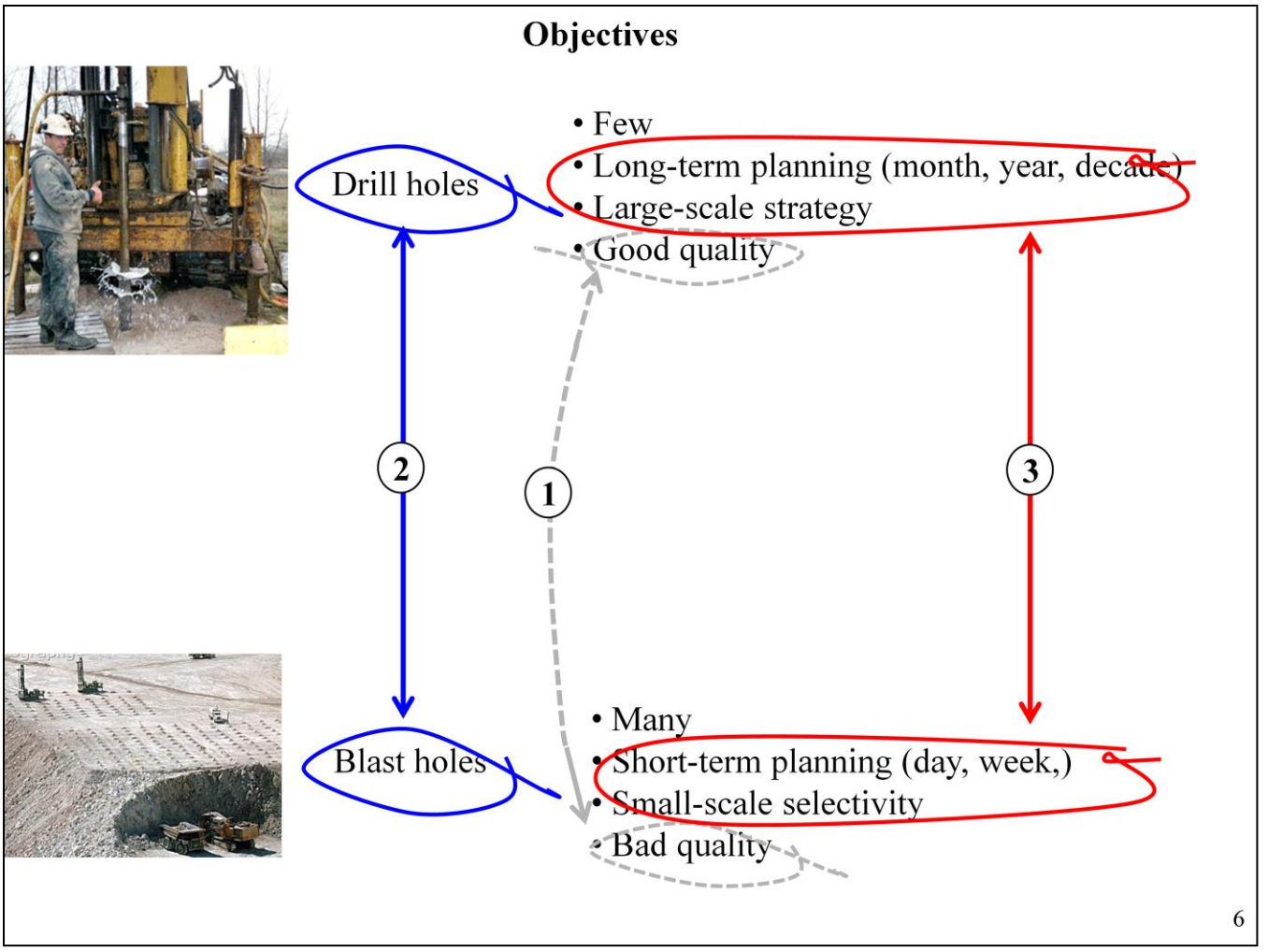
- Many
- Short-term planning (day, week,)
- Small-scale selectivity
- Bad quality

5

Finally, we often hear, without real justification, that the diamond drill holes are much better than the blast ones.

We ask the questions:

- Better how?
- Better for what?
- Is it true?



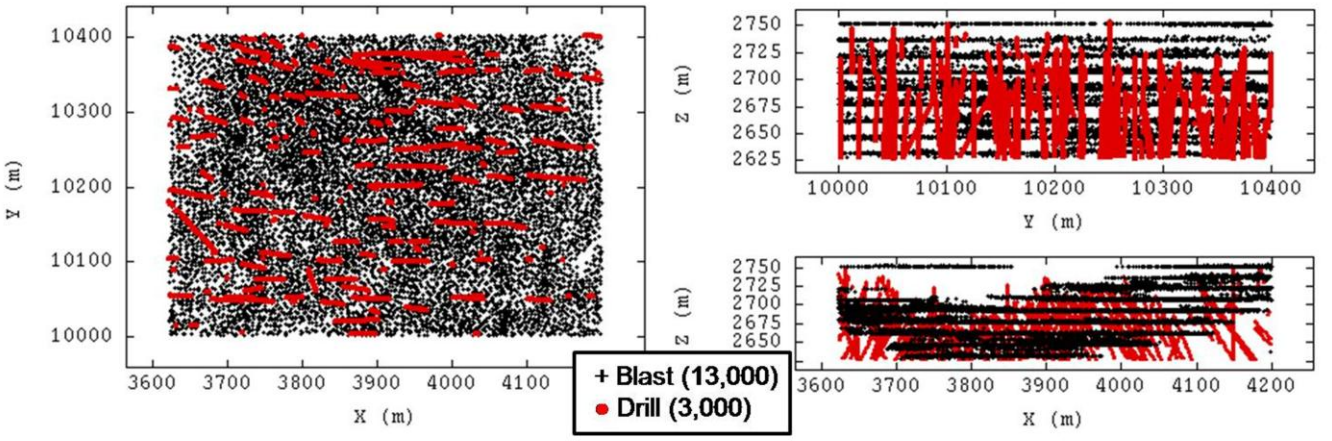
These are the reasons why this study is divided into three stages:

1 - Comparing the measurement qualities by comparing their variograms

2 - Establishing a formal link between the two measurements

3 – Deducing linear systems enabling us to use the two types of measurements together

Data

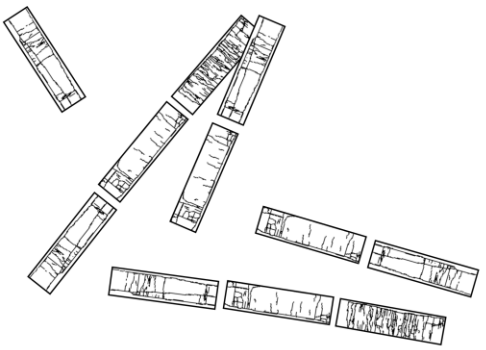


7

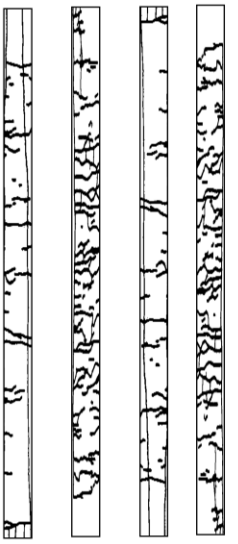
The data are from an open-pit copper mine in Northern Chile of where sub domain is analysed because it is almost homogeneously covered by around 3,000 drill-hole samples (3m long) and 13,000 blast-hole samples (15m long)

Drill holes, blast holes

Drill holes



Blast holes



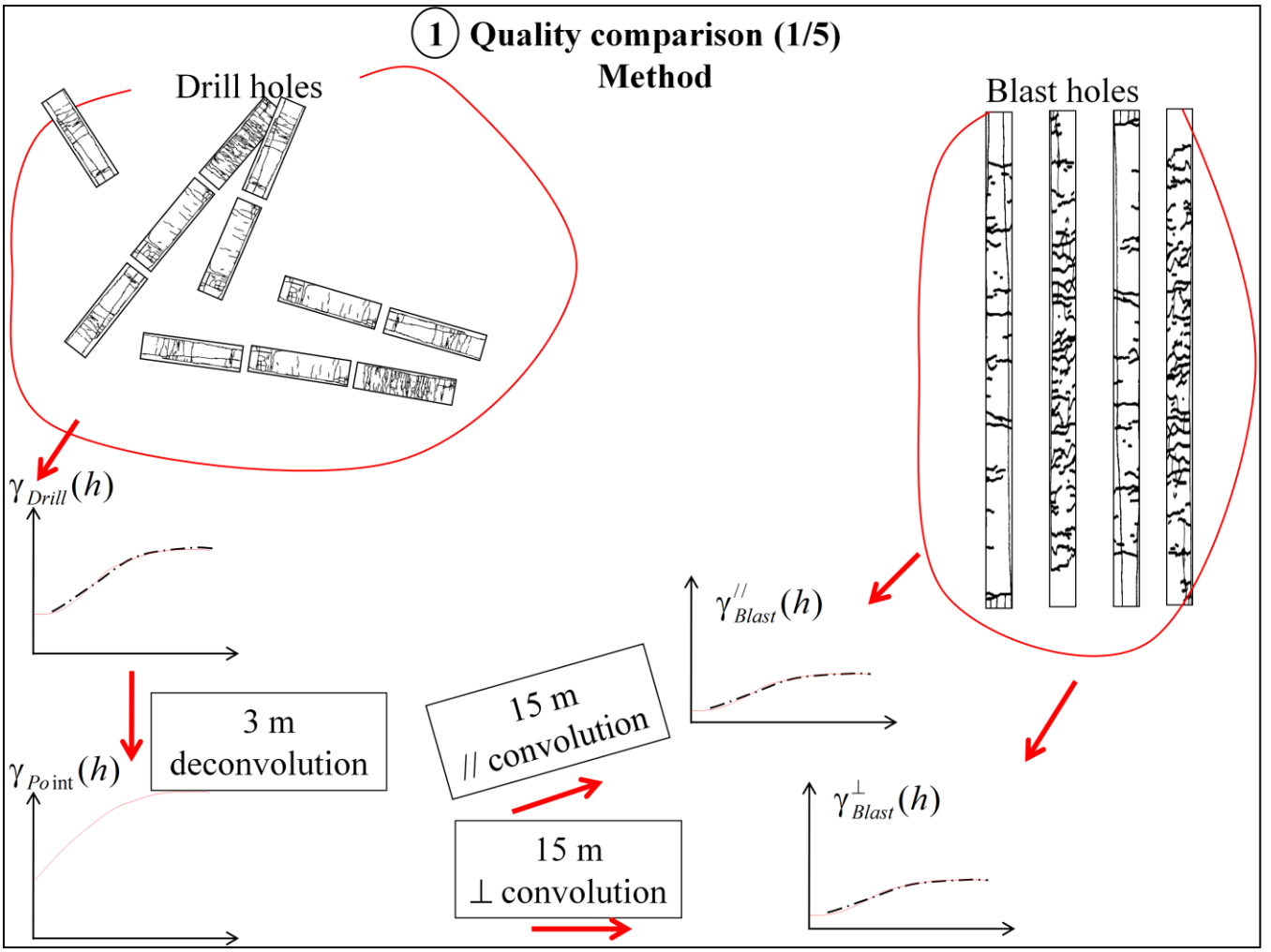
Blasts and drills differs by their sampling density, their support size and their orientation

Horizontally we have approximately one blast every 10 meters and vertically every 15 meters

For the drills, it is a bit more complex because they are not all vertical and the grid is not regular but we have approximately one drill hole every 50 meters horizontally, and every 3 meters along the drill hole.

3m is assumed to be the support of the drill samples; 15 meters is assumed to be the support of the blast samples.

The global sampling ratio is approximately one drill sample to four blast samples



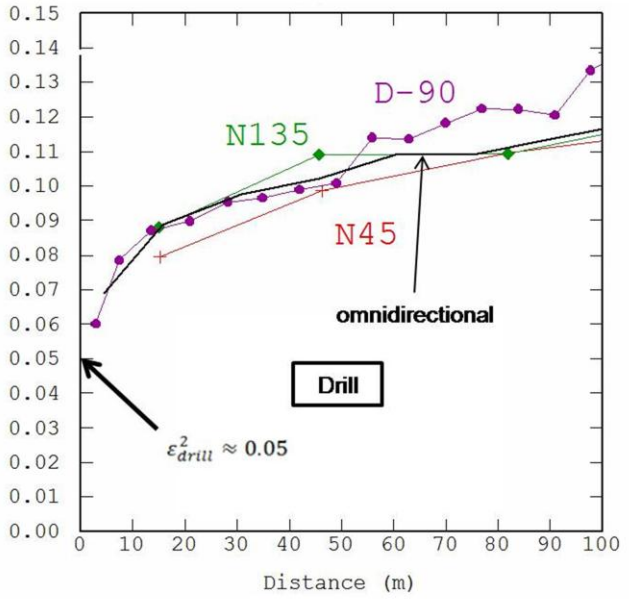
The geostatistical comparison between the two types of measurements is divided into two steps:

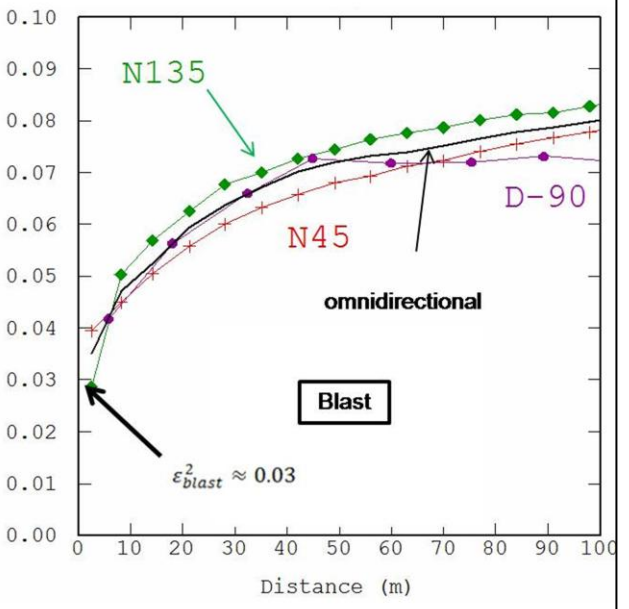
Starting from the drill variogram, identifying the basic structures that model its behavior and deducing the underlying point-support variogram

Making the theoretical convolution of the point variogram on 15-meter long supports and comparing it to the blast variogram

It is important to distinguish two situations: variogram calculation parallel or perpendicular to the regularization direction because the formulae are not the same

① Quality comparison (2/5)
Results





These are the variograms.

On the left, the drill variogram, on the right, the blast one

We notice that the behaviors are similar and that they both contain a high percentage of nugget effect

1 Quality comparison (3/5)
Charts

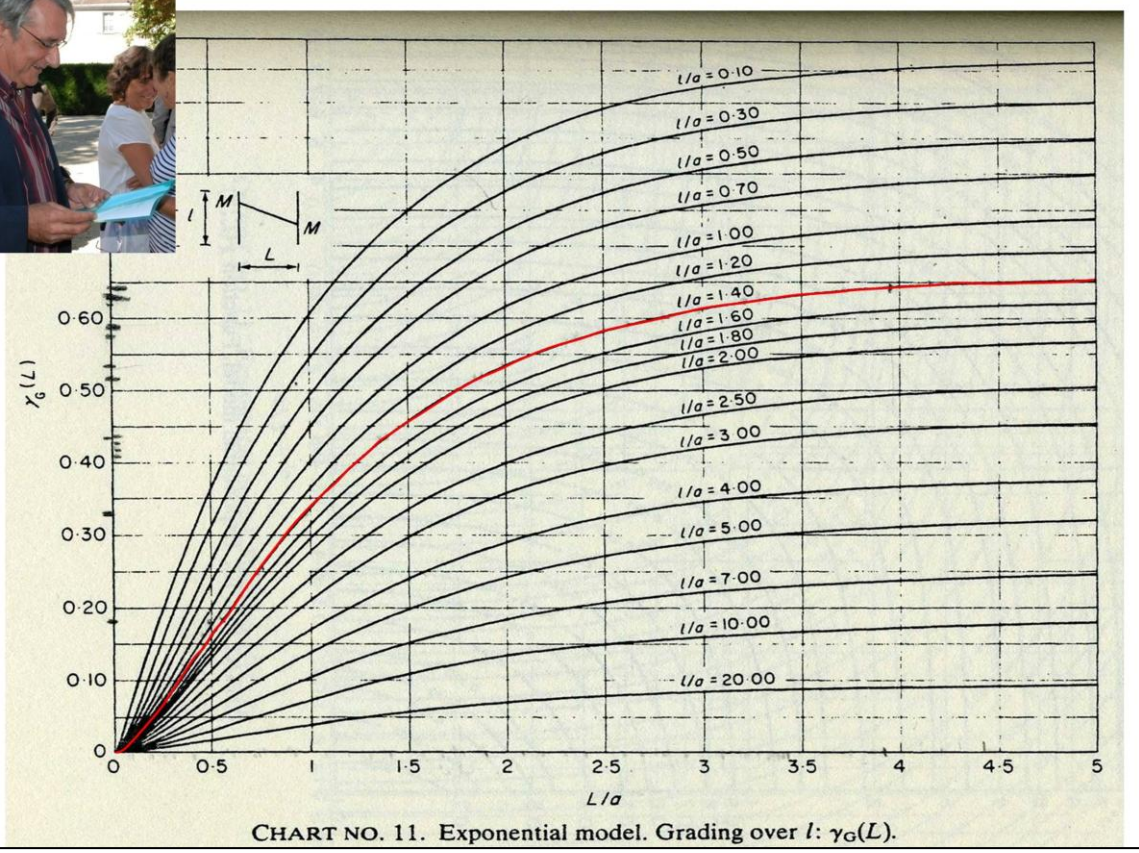
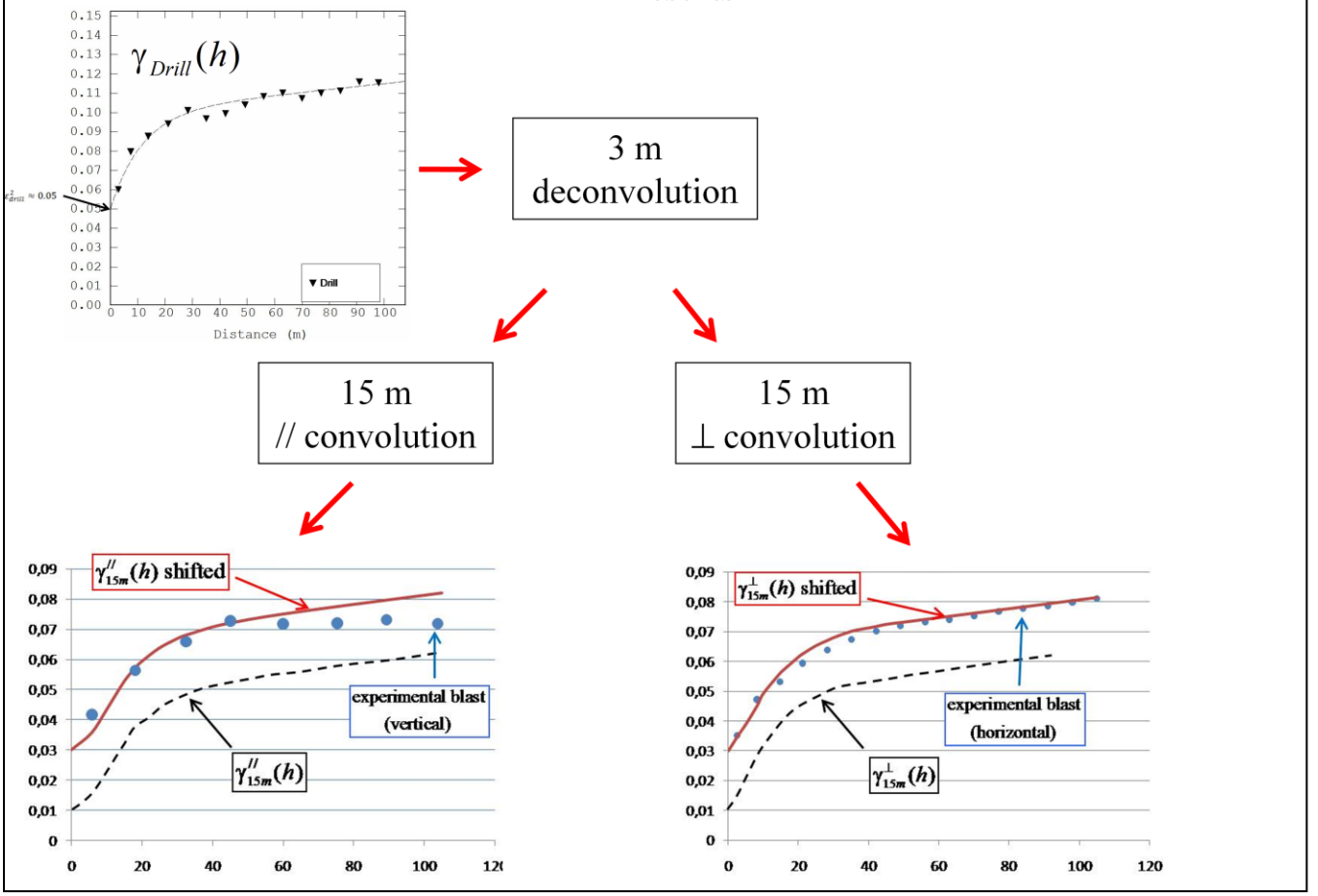


CHART NO. 11. Exponential model. Grading over l: $\gamma_G(L)$.

We do not detail here the calculations here, they are in the paper, we just show the charts to be used.

They were done by hand forty-five years ago by a man called Jacky Laurent, who retired last year…

1 Quality comparison (4/5)
Results



3 structures were identified on the drill variograms, nugget effect, exponential and linear with a weak slope

Then, an underlying point-support model was deduced

This model was theoretically regularized over 15 meters

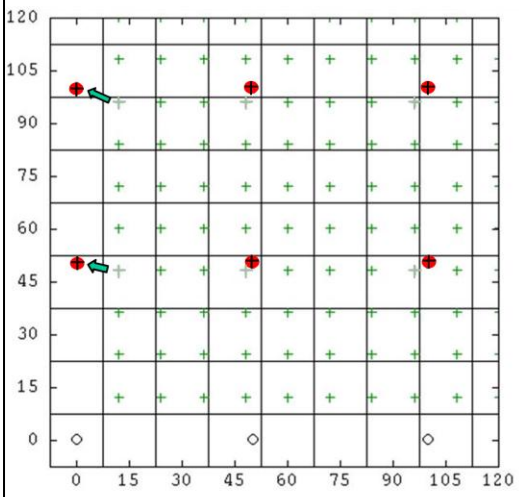
The bottom left-hand figure shows the vertical comparison. The dotted blue line represents the experimental vertical blast variogram, the dotted black line represents the present model and the red line the model we would obtain with a more realistic nugget effect.
One can see that apart from the problem of the nugget effect, the variation range is acceptable, even if the linear part of the theoretical structure does not appear in the vertical experimental blast variogram
The bottom right-hand figure shows the horizontal comparison. Again, apart from the nugget effect, the fitting is good.

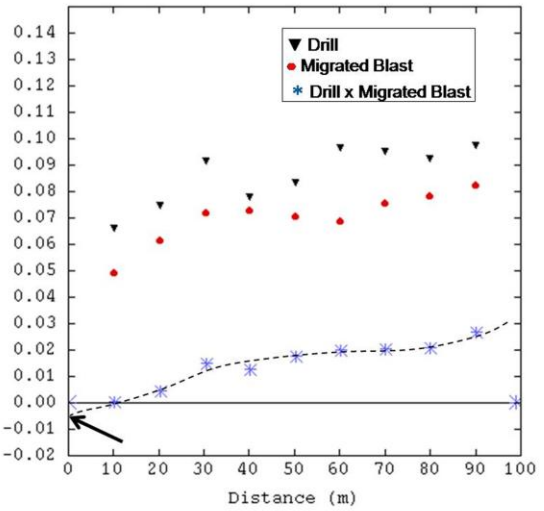
The first conclusion is that if we omit the problem of the nugget effect, we see that both blast and drill holes can be considered a regularization of the same phenomena in accordance with their respective supports.

But the approach followed up to now suffers from two uncertainties:
•The analyses are done independently.
•The analyses refer to the drill-hole nugget which we assumed to be a "natural" micro structure; is this true?

To answer these questions, cross variograms must be calculated but we do not have any location with both measurements, so a migration is necessary.

① Quality comparison (5/5)
Cross analyses & conclusion





In order to obtain a significant number of measurements at the same location, around 1,000 blast samples were migrated to drill locations when the migration distance did not exceed 10 meters.

The right-hand figure presents the variograms.

Red points indicatethe migrated blast variogram, black triangles show the drill variogram and the stars represent their cross variogram which does not show a significant nugget effect, possibly a small negative one without anything like the effects encountered on the individual variograms.

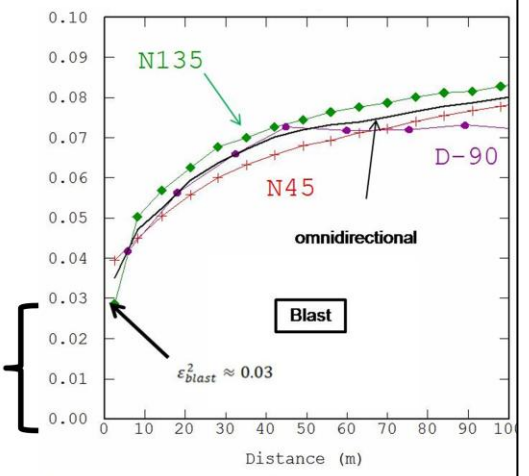
The conclusion is that the drill-holes have their own errors, independent of the blast ones, and the two measurements share only the structured parts of the variogram: the exponential and linear structures.

② Formal link

$$Y_{blast}(x,y,z) = Y(x,y,z) * p_{15m}(z) + R_{blast}(x,y,z)$$

$$\gamma_{blast}(h) = \gamma_{15m}(h) + \gamma_{R_{blast}}(h)$$

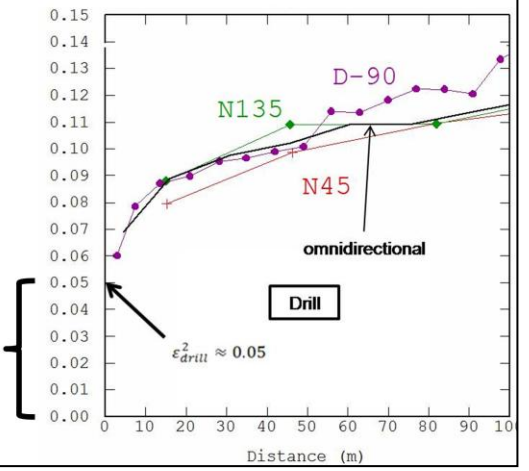
Blast sampling error



$$Y_{drill}(x,y,z) = Y(x,y,z) * p_{3m}(z) + R_{drill}(x,y,z)$$

$$\gamma_{drill}(h) = \gamma_{3m}(h) + \gamma_{R_{drill}}(h)$$

Drill sampling error

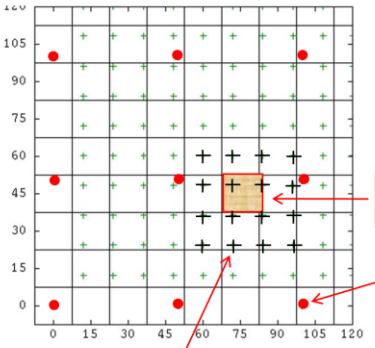


Finally we are able to establish a formal link between blast and drill measurements.

3 Consequence

Block modelling

$$\begin{pmatrix} C*\mathcal{P}_{3m} & C*p_{3m}*p_{15m} & 1 \\ C*p_{15m}*p_{3m} & C*\mathcal{P}_{15m}+C_R\delta(0) & 1 \\ 1 & 1 & 0 \end{pmatrix} \begin{pmatrix} \lambda \\ \lambda' \\ \mu \end{pmatrix} = \begin{pmatrix} C*p_{3m}*p_V \\ C*p_{15m}*p_V \\ 1 \end{pmatrix}$$



Block kriging using: • +

$Y_V(u)$

$Y_{drill}(u_i)$

λ_i

$Y_{blast}(u_j)$

λ'_j

$$Y_V(u) = \sum_i \lambda_i Y_{drill}(u_i) + \sum_j \lambda'_j Y_{blast}(u_j)$$

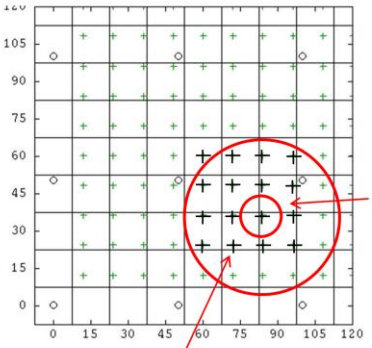
… and this link makes it possible to deduce linear systems like this one where the way to use blast and drill together in a single system is defined.

Thus, it becomes possible to improve the block model, based on drill holes, by integrating the blast holes as they are.

It also becomes possible to predict the production of the following days more accurately.

Filtering the blast error

$$\begin{pmatrix} C * \mathcal{P}_{15m} + C_R\,\delta(0) & 1 \\ 1 & 0 \end{pmatrix} \begin{pmatrix} \lambda \\ \mu \end{pmatrix} = \begin{pmatrix} C * \mathcal{P}_{15m} \\ 1 \end{pmatrix}$$



$$Y^{*}_{blast}(u) = \sum_j \lambda_j Y_{blast}(u_j)$$

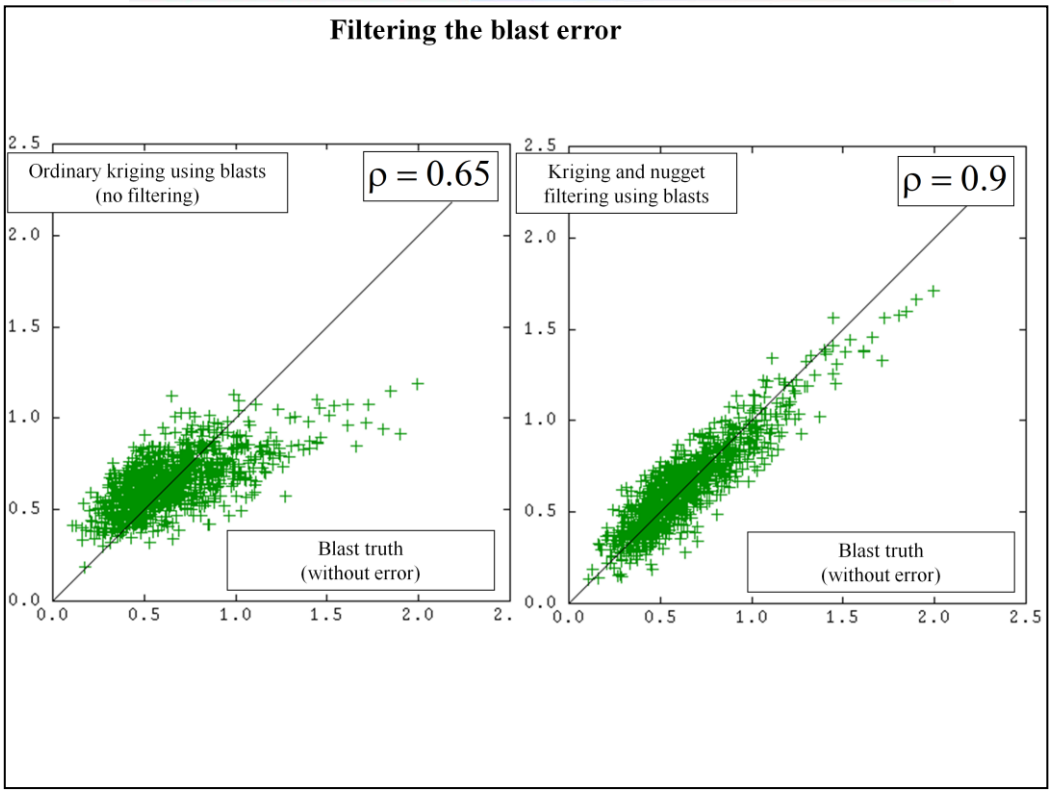
$Y_{blast}(u_j)$
λ_j

One can also use this link to remove the blast error. The filter can be applied to each blast measurement, using a local neighborhood of surrounding blast samples. The system to be used is presented symbolically with a matrix formalism.

Such systems have been tested on a realistic simulation where everything is known (true point value, true block values, blast with or without errors).

The results will be shown at a congress next July in Northern Chile, but I can show you here one of the result concerning the filtering of the blast error by kriging.

For comparison, estimation is made by kriging with no filtering.



➢Here are the results

➢On these scatter diagrams, the horizontal axis represents the true blast without any sampling error

➢On the left scatter diagram, the vertical axis is a usual kriging. The correlation with the truth is 0.65

➢On the right, when the filtering is activated, the correlation increases to 0.9. Why?

➢Because with filtering, the kriging neighborhood can incorporate the target point where the filter is applied. This point takes a high kriging weight (more than 65%). Although noisy, this point is closer to the truth than any average based on surrounding points which explains why the filter estimate is closer to the truth

➢ So finally, the advantage of this linear system is to enable the kriging neighborhood to incorporate the target point information

Conclusions

- Consistency
- Blast sampling errors, drill sampling errors
- (Co)kriging linear systems

In this deposit – and more generally, in this company, diamond drill hole grades and blast hole grades are consistent in the sense that, apart from the nugget effect, the structured part of their respective variograms follows the theoretical laws of regularization.

Concerning the nugget effects, we discover, by cross-analyses, that there is no natural micro-structure in the underlying point grade and the large nugget effects encountered on the variograms are due to blast and drill measurement errors.

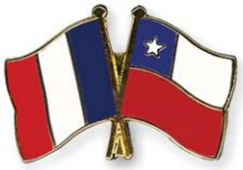
In conclusion, some linear systems are proposed for removing the nugget effects from the data, and, more importantly, using blasts and drills together for short-term planning in mining.

These systems, among many other potential ones, easy to demonstrate, result directly from the formal link established here between blast and drill holes.

Before these systems are applied, the link must be verified according to the methodology presented here.

Acknowledgment

CODELCO Produciendo Futuro
Codelco Chili



MINES ParisTech

- Codelco
- Chile
- France
- Paris School of Mines

Thank you for your attention

O yes I must apologize in advance: I have exactly 40 minutes left to reach the train station and I hope the taxi I ordered is waiting for me. Please, do not be surprised if I run out of the room when finished. I am not ill, I am not running away from the issues, I just have a train to catch….

Any question?