MINE PLANNING IN A PHOSPHATE DEPOSIT

By

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ABSTRACT

In the early stages of the planning of a new exploitation, the error in ore reserve estimation is an important factor that must not be disregarded. As this error can be computed by geostatistical methods, the risk of the venture can be calculated for different recognition patterns in a certain assumption of economical conditions.

A case story is described for an open pit phosphate deposit in which grade/tonnage curves and their confidence intervals are related to an economic function for three drilling patterns and decisions are taken on the basis of cost and value of supplementary information.

INTRODUCTION

A phosphate deposit located in the State of Goias, Brasil, was recognized by a 100 x 100m regular grid of 134 drillings. Pieces of core from these drillings were analysed for P_2O_5 and CaO and grades in P_2O_5 from apatite were computed for each 1m length sample. Blocks 50 x 50 x 10m were built over all the deposit for selection purposes in this stage of planning. For each of these units, a kriging procedure as described by Matherton (1970) was adapted in order to estimate the average grade and kriging variance.

As the deposit is not yet completely recognized in depth, global ore reserve estimation is unneeded, but some decisions must be taken about the economics of the venture in the zone near the surface.

For this zone, an open pit and a pilot plant were designed and strategies of exploitation must be compared.

STRUCTURAL ANALYSIS

The Variogram is the basic tool of Geostatistics.

The mathematical expression of this function is:

$$2\gamma(\vec{h}) = \{[Y(\mu+\vec{h}) - Y(\mu)]^2\} \qquad (1)$$

$\gamma(\vec{h})$ is the variogram,

$\gamma(\mu+\vec{h})$ and $Y(\mu)$ are the values taken by the Regionalized Variable in two points linked by the vector $\vec{h}$.

This function, as Matheron (1970) and David (1975) showed, depends on the sample volume where $Y(\mu)$ is calculated.

In the case of this deposit, the basic information includes 5m spaced channel samples which must be used in computation of variograms for small scale study. A numerical deconvolution as described by David (1975) was performed to recover punctual variograms from channel samples and core drilling samples.

An example of such a variogram in EW direction is shown in Fig. 1 and a theoretical model of spherical type was fitted.

The basic parameters shown in Fig. 1 are:

Co - nugget effect

C - sill

α - range

The meaning of these parameters are discussed by Matheron (1970), David (1975), Journel (1975).

In particular, the range is the distance

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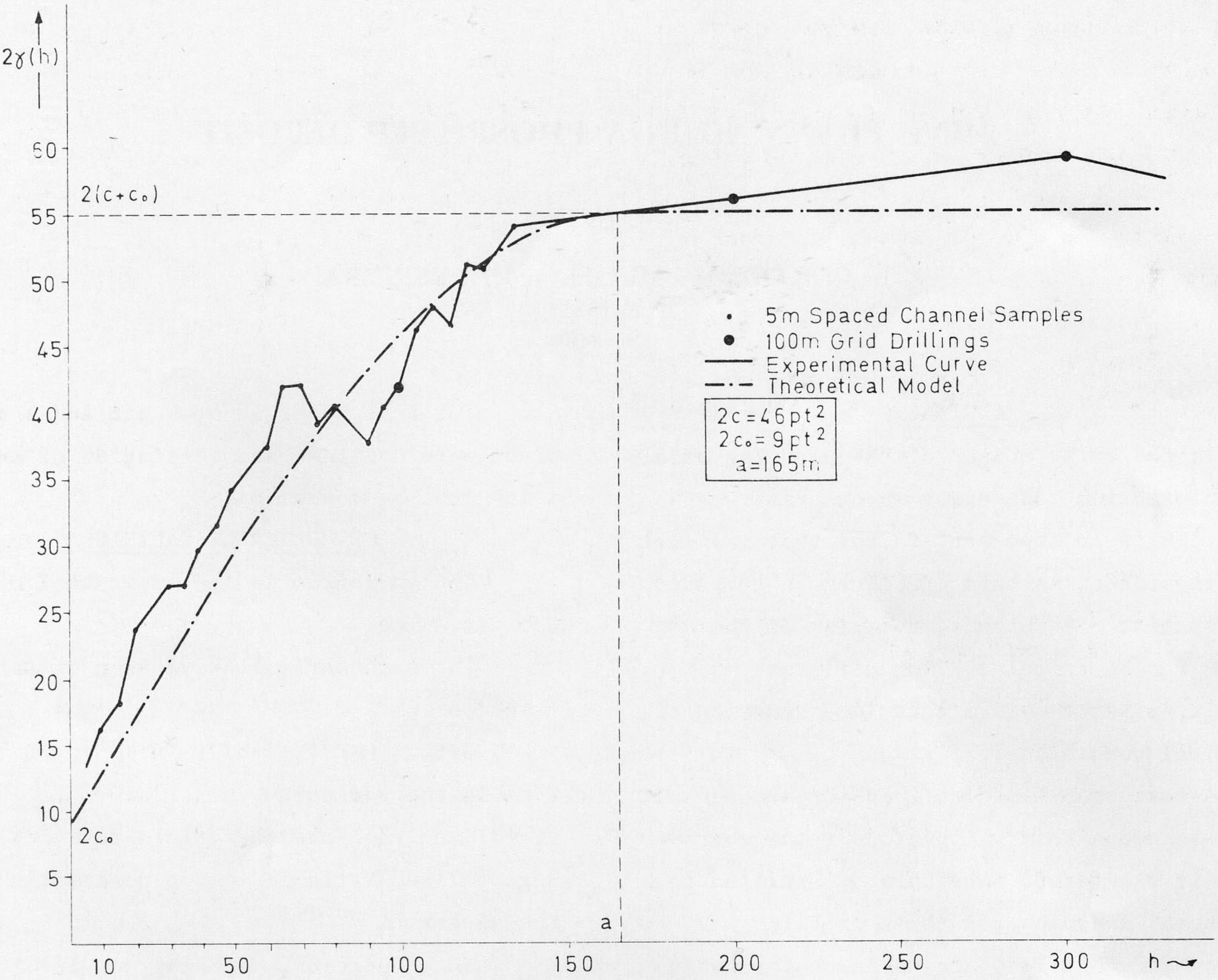

Fig. 1 EW Variogram of accumulation in P_2O_5.

for which the autocorrelation function vanishes.

Variograms of the same type were computed for NS and vertical directions and a geometric anisotropy was detected (ranges of 345m and 37.5m).

The Regionalized Variable used is the accumulation in P_2O_5 (grade x thickness) from apatite.

KRIGING

For each block, the kriging technique provides an optimal estimation of the average grade and the variance of this estimation. Assuming a normal distribution for the average grade estimate $\dot{Z}$, the real value Z of the grade in a block lies in the interval

$$\dot{Z} - 2\sigma_K \leqslant Z \leqslant \dot{Z} + 2\sigma_K \quad (2)$$

at the 95% probability level.

If one takes a set of n blocks, the confidence interval of the average grade is:

$$\dot{\bar{Z}} - \frac{2\bar{\sigma}_K}{m} \leqslant Z \leqslant \dot{\bar{Z}} + \frac{2\bar{\sigma}_K}{m} \quad (3)$$

where $\dot{\bar{Z}}$ is the kriging estimate of the average grade of n blocks and $\bar{\sigma}_K^2$ is the average kriging variance of n blocks. In other words, there is a risk of 2.5% that the average grade of a certain set of n blocks is lower than $\dot{\bar{Z}} - \frac{2\bar{\sigma}_K}{m}$.

Using all the available information, a block by block estimation for all units of the deposit was performed using a three dimensional kriging program that provides estimates $\dot{Z}$ and variances σ_K^2.

For details in kriging theoretical basis, see Matheron (1970) and for practical applications, see Journel (1975) and David (1975).

GRADE/TONNAGE CURVES

A small area in the deposit was chosen to build grade/tonnage curves and study the sensitivity of an economic function to the confidence intervals of those curves.

The selected area is shown in Fig. 2.

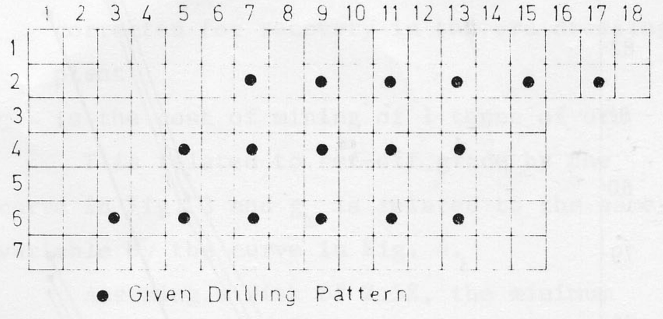

Fig. 2 Location of the blocks and drillings in the selected area.

For each of the 445 blocks of this area, a grade/tonnage curve was computed on the basis of kriged values for grades.

This curve can be used for purposes of planning at this stage as David (1972) suggested.

When more information is available, namely, smaller exploitation units, loader machines to be used, blast holes geometry, etc., a short term planning must be done using the method developed by Matheron (1975) and applied by Marechal (1975).

The grade/tonnage curve for this area is shown in Fig. 3 and the grade/average grade curve for the same area is shown in Fig. 4.

It is assumed that there is no error in the density of the ore and so the number of blocks with grade higher than a certain cut-off is proportional to its tonnage and no confidence intervals are assigned to this curve.

On the other hand, confidence intervals for the average grade can be computed from 3 and the curve of Fig. 4 shows these intervals for the 95% probability level.

SUPPLEMENTARY DRILLING PATTERNS

In the same area, the effect of a first

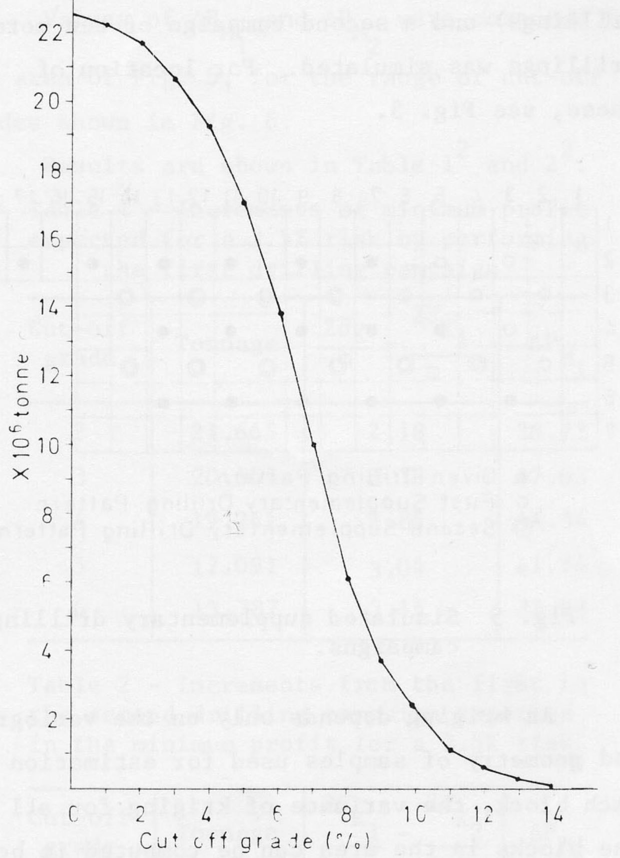

Fig. 3 Grade/tonnage curve.

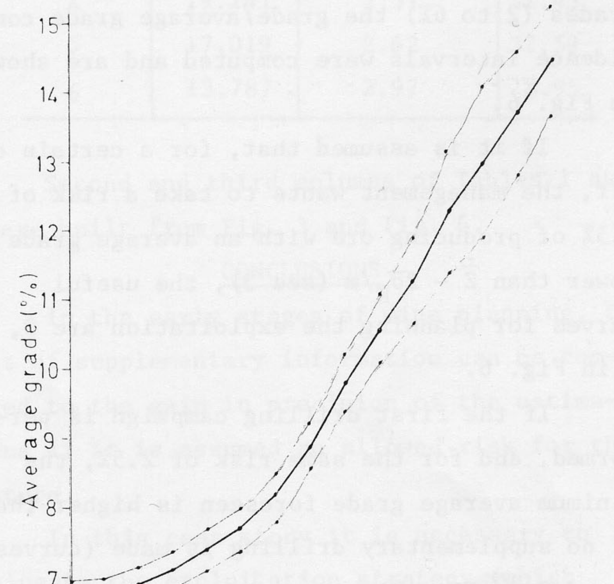

Fig. 4 Grade/average grade curve with 95% confidence intervals.

supplementary campaign of seven drillings of about 30m length (the same as the given drillings) and a second campaign of ten more drillings was simulated. For location of these, see Fig. 5.

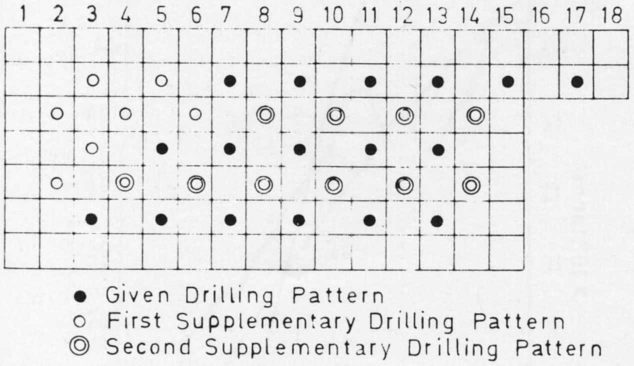

Fig. 5 Simulated supplementary drilling campaigns.

As kriging depends only on the variogram and geometry of samples used for estimation of each block, the variance of kriging for all the blocks in the area can be computed in both cases (first and second supplementary drilling campaigns).

In the zone of the interesting cut-off grades (2 to 6%) the grade/average grade confidence intervals were computed and are shown in Fig. 6.

If it is assumed that, for a certain cut-off, the management wants to take a risk of 2.5% of producing ore with an average grade lower than $\dot{\bar{Z}} - 2\bar{\sigma}_K/m$ (see 3), the useful curves for planning the exploitation are 0, 1, 2 in Fig. 6.

If the first drilling campaign is performed, and for the same risk of 2.5%, the minimum average grade foreseen is higher than if no supplementary drilling is made (curves 1 and 0 in Fig. 6).

RISK ANALYSIS

Assuming a simple linear model for an economical function relating tonnage and average grade, the global Profit P for all

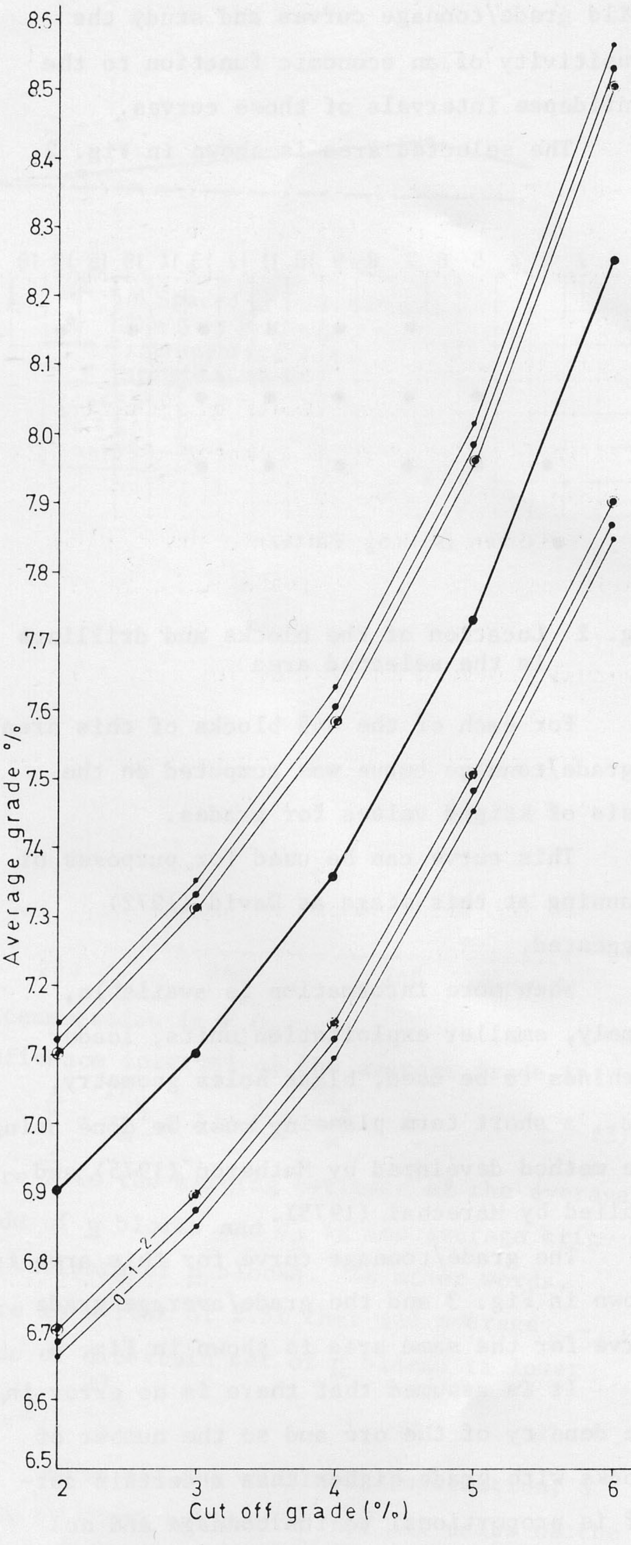

Fig. 6 Grade/average grade curves and confidence intervals for the given drilling pattern (0), first supplementary drilling campaign (1) and second supplementary drilling campaign (2).

blocks mined can be written as -

$$P = T(g_m v - C) \quad (4)$$

where:

T - is the tonnage of blocks mines (tonnes)

g_m - is the average grade of blocks mined (%)

v - is the selling price of 1 tonne of product corrected for recovery in the ore dressing plant

C - is the cost of mining of 1 tonne of ore

T is related to cut-off grade by the curve in Fig. 3 and g_m is related to the same variable by the curve in Fig. 4.

Assuming a risk of 2.5%, the minimum Profit expected for a certain cut-off can be calculated from 4 using the lower confidence interval (curve 0 in Fig. 6) for computing $g_m - 2\bar{\sigma}_K/m$.

So, there is 2.5% of probability of obtaining a Profit lower than P_M:

$$P_M = T\left[(g_m - 2\bar{\sigma}_K/m)v - C\right] \quad (5)$$

If the first supplementary campaign is performed, a cost S_1 of drilling must be compared to the gain of precision in estimation:

$$P_{M_1} = T\left[(g_m - 2\bar{\sigma}_{K_1}/m)v - C\right] - S_1 \quad (6)$$

the second drilling campaign leads to:

$$P_{M_2} = T\left[(g_m - 2\bar{\sigma}_{K_2}/m)v - C\right] - S_2 \quad (7)$$

where S_2 is the cost of drilling.

ΔP_{M_1} is the increment of the minimum (at a 2.5% risk) profit expected by performing the first campaign:

$$\Delta P_{M_1} = P_{M_1} - P_M \quad (8)$$

$$\Delta P_{M_1} = T\left(\frac{2\sigma_K}{m} - \frac{2\sigma_{K_1}}{m}\right)v - S_1 \quad (9)$$

if ΔP_{M_1} is positive, it is interesting, in the assumptions made, to perform the supplementary drilling.

ΔP_{M_2} can be written as $P_{M_2} - P_{M_1}$ or

$$\Delta P_{M_2} = T\left(\frac{2\bar{\sigma}_{K_1}}{m} - \frac{2\bar{\sigma}_{K_2}}{m}\right)v - S_2 \quad (10)$$

and measures the interest of the second drilling campaign, compared with the first one.

Values of ΔP_{M_1} and ΔP_{M_2} were computed for the area of Fig. 5, for the range of cut-off grades shown in Fig. 6.

Results are shown in Table 1[2] and 2[2].

Table 1 - Increments of minimum profit expected for a 2.5% risk by performing the first drilling campaign

Cut-off grade	Tonnage	$\frac{2\bar{\sigma}_K}{m} - \frac{2\bar{\sigma}_{K_1}}{m}$	ΔP_{M_1}
2	21.665	2.18	36.73
3	20.655	2.33	37.63
4	19.241	2.85	44.34
5	17.091	3.04	41.24
6	13.787	3.15	32.93

Table 2 - Increments from the first to the second drilling campaign expected in the minimum profit for a 2.5% risk

Cut-off grade	Tonnage	$\frac{2\bar{\sigma}_{K_1}}{m} - \frac{2\bar{\sigma}_{K_2}}{m}$	ΔP_{M_2}
2	21.665	2.35	38.91
3	20.655	2.36	36.75
4	19.241	2.31	32.45
5	17.019	2.62	32.59
6	13.787	2.97	28.95

Second and third columns of Tables 1 and 2 were built from Fig. 3 and Fig. 6.

CONCLUSIONS

In the early stages of mine planning, the cost of supplementary information can be compared to the gain in precision of the estimations if it is assumed an allowed risk for the venture.

In this case story it is necessary to conjugate the exploitation strategy (which depends mainly on the cut-off grade) with the plant strategy (which depends mainly on the average grade). For a certain cut-off grade, it can be foreseen the expected average grade

2. For propriety reasons values are multiplied by a constant.

from the curve of Fig. 4.

The Profit is a function of this average grade, the lower limit of which may be fixed by a maximum allowed risk.

Supplementary drilling provides narrower confidence intervals for average grade curves and so, for a fixed risk, the minimum profit expected will be higher.

Drilling patterns used in this case story are arbitrary and so conclusions are empirical but a step-by-step procedure may be attempted to optimize the method.

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