UNIVERSITE GRENOBLE ALPES

# Deposit modelling : Geostatistical approach

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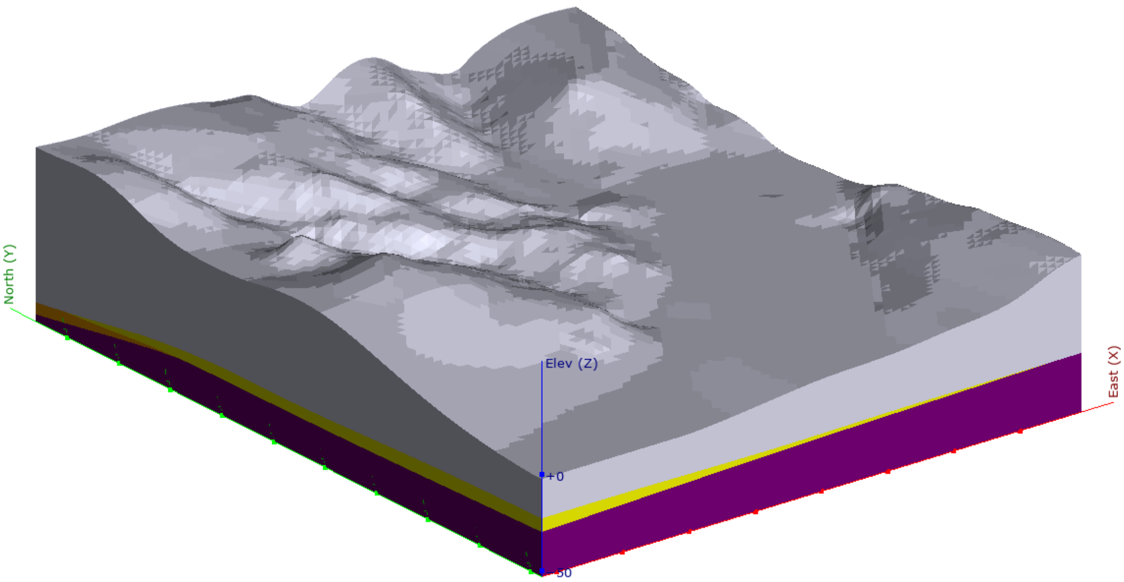
M2 Géoressources

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2020

**Geological Modelling with Leapfrog**

With José Almeida

**January 2021**

UGA UFR PhITEM Université Grenoble Alpes

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**Cover**

Geological model of Farim Deposit.

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# 1 Introduction

Geostastistics is a branch of mathematics, most often applied to the study of mineral resources and reserves. This work will propose to model the spatial distribution of natural resources in the case of the Farim phosphate deposit. This approach, which precedes the phase of mining exploitation, is indispensable to estimate and assess the economic viability of an orebody. Indeed for geologists, some measures such as the grades and tonnage of a deposit, as well as the uncertainties associated to them are crucial to characterise the deposit or understand its formation.

# 2 Localisation and deposit description

The Farim deposit is located in the northern part of Guinea-Bissau, close to the Cacheu River as shown in the figure. 1. This sedimentary phosphate deposit was discovered in the early 1980s. (Charifo et *al.*, 2014). About 69 boreholes were realised within a surface of 0.5 km$^2$ (Prian, 2014), which enabled the acquisition of data such as the punctual lithologies and geometries of the different layers. This deposit of sedimentary origin developed in a shallow marine-and-bay paleogeographic trap, and presents two parts of interest, namely FPA and FPB. These formations, that were deposited during the Eocene (Charifo et *al.*, 2014) present phosphate mineralisations with (FPB) or without (FPA) carbonates, which will be the main focus of this study.

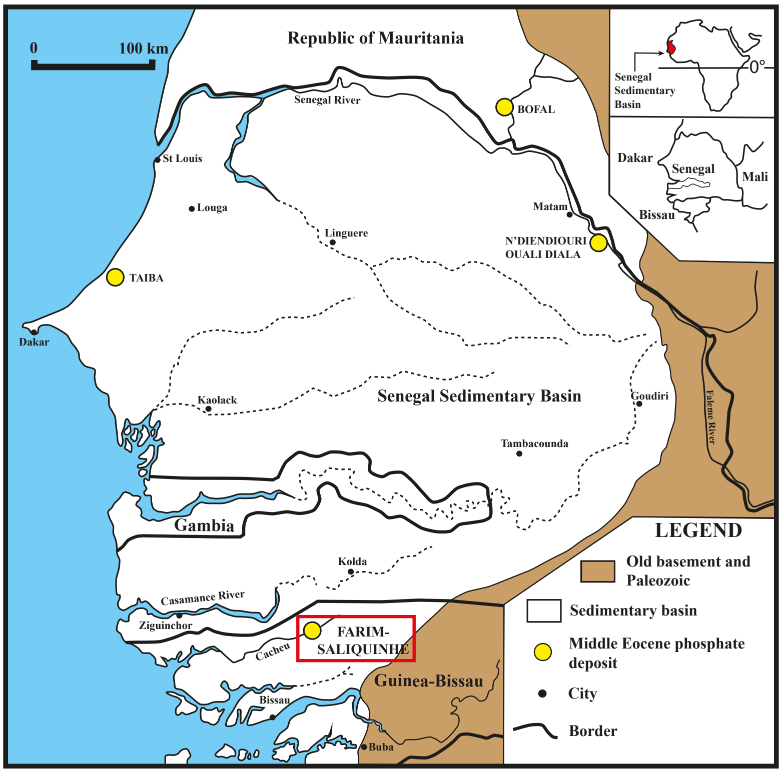



Figure 1 – Location of the Farim deposit. According to Prian (2014).

Morphological, topographical and logging data were used to carry out the geological and economic modelling of the deposit.

# 3 Geological Modelling

An implicit modelling of the deposit was realised using the Leapfrog software. In the processed case, the modelling is based on a distance estimator RBF (Radial Basis Function) which makes it possible to extrapolate the data already known to build iso-surfaces (distance zero) and thus to demarcate the deposit. (Leapfrog, 2020). The figures 2 and 3 respectively show the topographical and well data, and then the geological model obtained from these data. On the geological section of the figure 3b, the cover seems to be very thick, it is therefore already possible to expect that this significant width will have a considerable impact on the exploitation cost of the inferior layers. In the end, the FPA and FPB levels are located below the cover and just above the base.

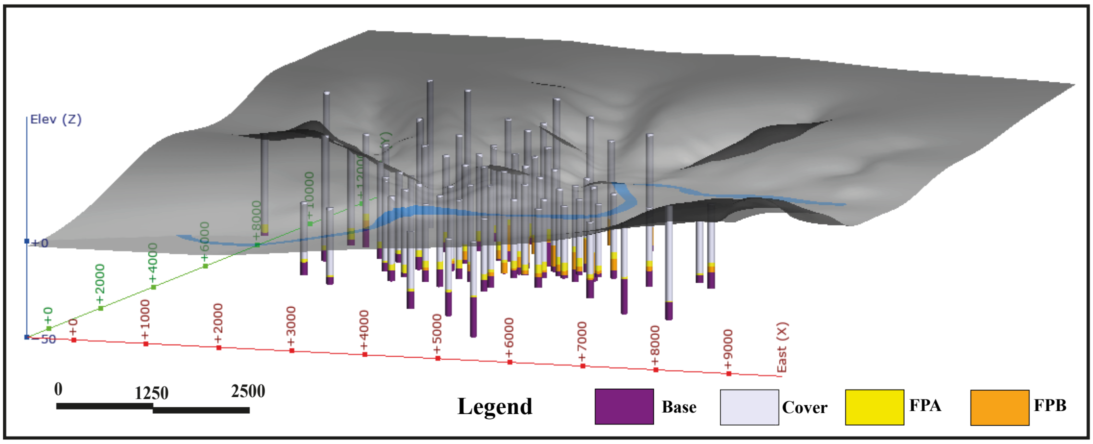



Figure 2 – Topography of the study area and logging data

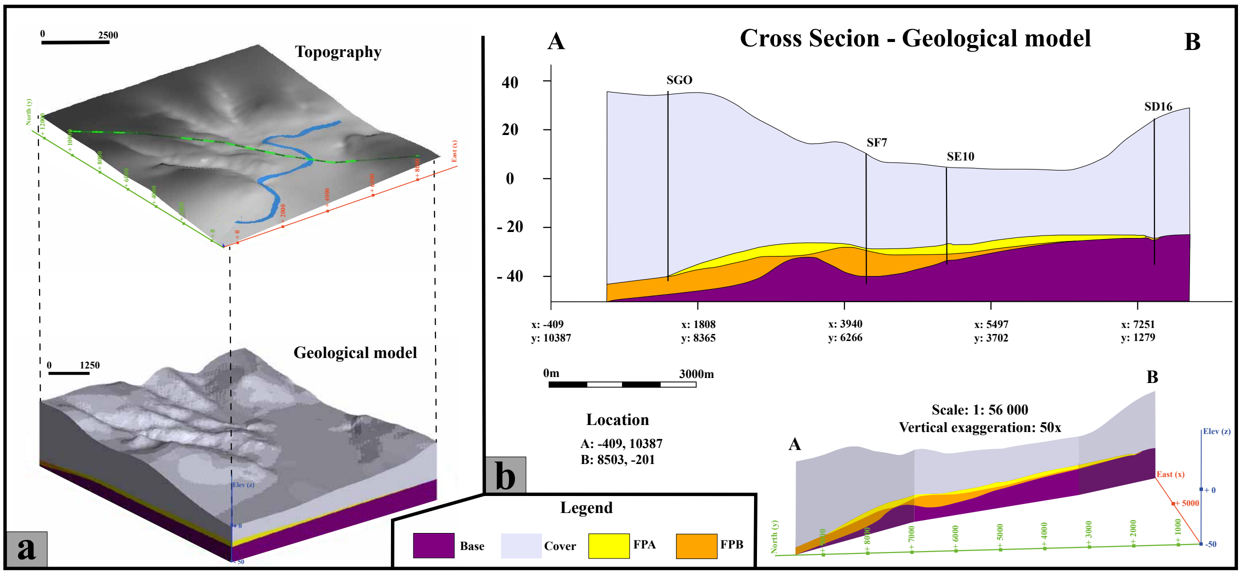



Figure 3 – (a) Topography and geological model of the Farim deposit. (b) 2D and 3D geological section from the geological model created.

# 4 Geostatistic Modelling

Geostatistical modelling is an essential element in the evaluation of a deposit's reserves. It aims at targetting the layers of interest and to evaluate their phosphate content as well as their proportion in relation to the volume of ore. The figure 4 shows the $P_2O_5$ grades of each layer obtained from the well data. This horizontal representation of the data shows significantly higher median phosphate values for the FPA and FPB layers. The trend for the FPA layer is much higher than for the other three layers. Although the FPB layer has values sometimes close to those of the sediment cover, the latter shows higher average grades. Associated with this first representation of the data is a histogram representing the volume of rock for each grade of $P_2O_5$ for the FPA and FPB layers together. This shows the two average grades of FPA and FPB, but also shows that the high phosphate concentrations in the FPA layer have a much better grade than in the FPB layer, while for lower grades, the grade between the two units is relatively close.

In a second step, the well data must be interpolated to the entire geological model that was previously constructed. However, it is rather difficult to estimate spatially the continuity of the grade from the borehole measurements. For this, a classic method in geostatistics is the variogram method (Matheron, 1963). This technique is based on the principle that two observations or measurements located close to each other should, on average, be more similar than two observations or measurements located far apart. Thus, the variogram takes into account not only the distance between the measurement point and the point of estimation, but also the distances between the measurements in pairs. The major advantage of this method is that it is objective, since it only seeks to estimate statistical parameters from the data and not to impose a model a priori. The figure 5 shows the variogram of the FPA layer. The main directions are horizontal, with a South-North spatial correlation of about 2.2 km and West-East correlation of 1.2 km for a vertical correlation of only a little more than 3m. This anisotropy results in a better continuity of the deposit in the North-South direction.

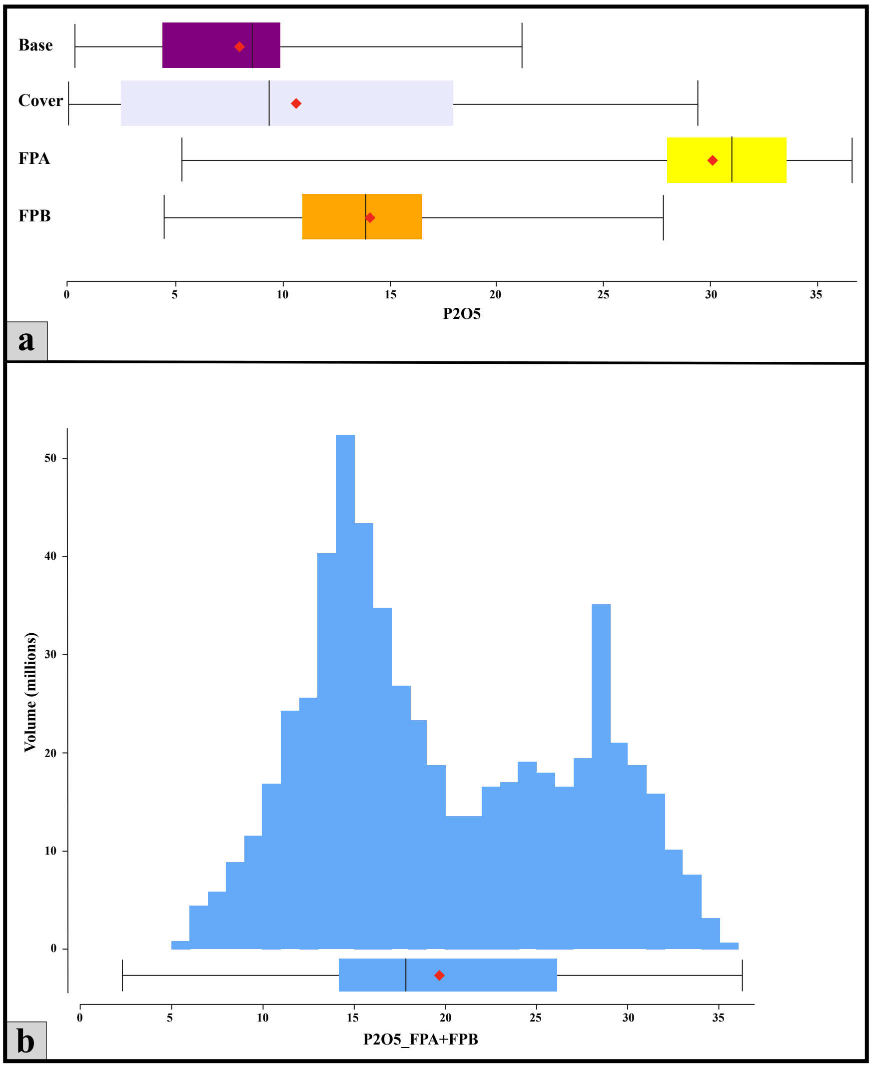



Figure 4 – a. Box plot of $P_2O_5$ grade for each layer of the model. b. Histogram representing the volume of rock for each grade of $P_2O_5$ for the FPA and FPB layers (merged)

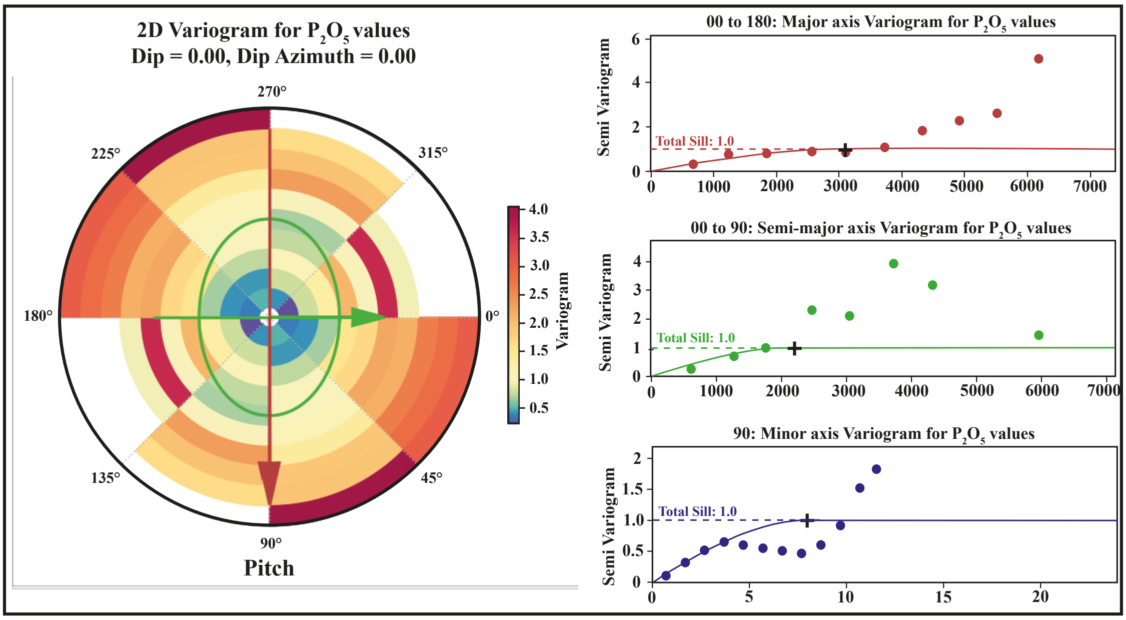
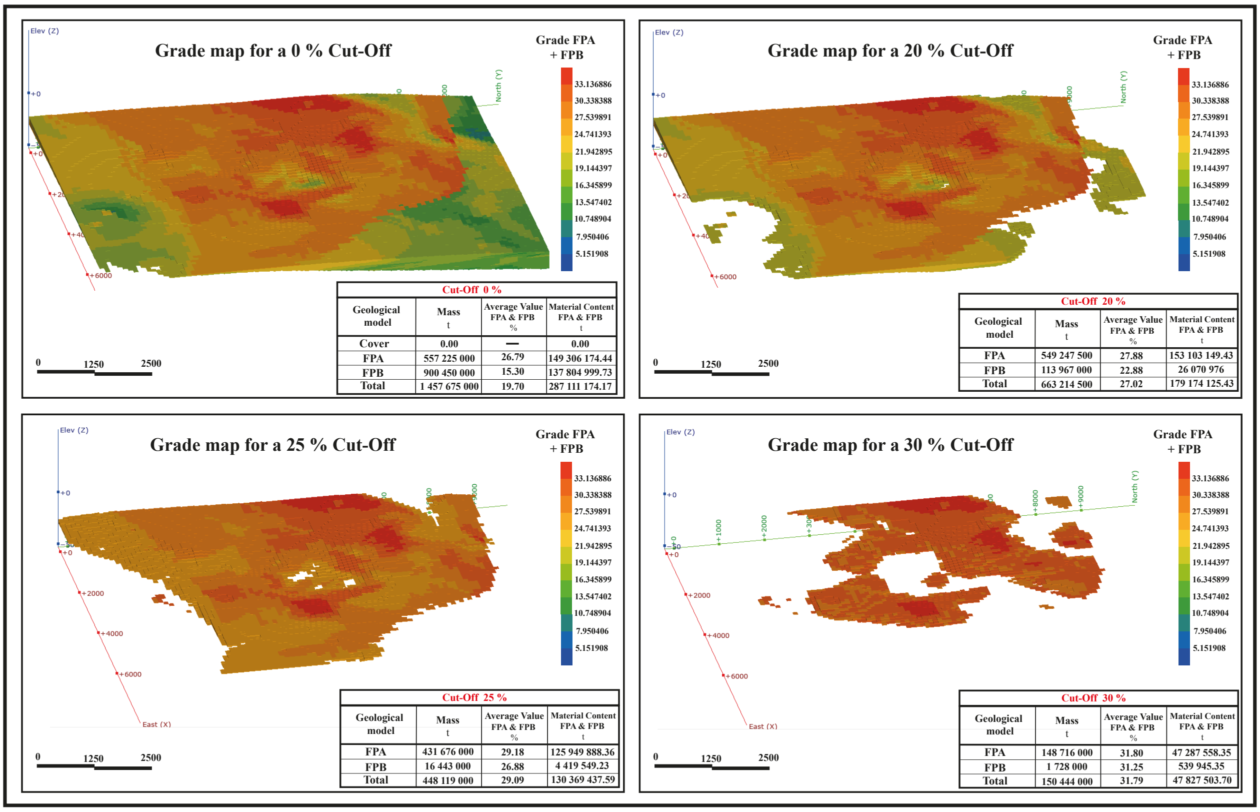



Figure 5 – Variogram for $P_2O_5$ content in FPA layer. The red axis is the NS principal direction, the green one is the WE direction. A third direction (in blue) not shown here, is for the vertical direction.

# 5 Mining reserve

The interpolation given by the variograms enabled the creation of the maps of the figure 6 and the curves of the figure 7. The spatial evolution of the grade is given for 4 different cut-offs (superior to the indicated cut-off value), to which a table is associated. It presents the mass, the maximal grade and the estimated phosphate quantities for the FPA and FPA layers. That makes it possible to give quantitative and qualitative data not only about the repartition of the grade, but also about its increase with the decrease of tonnage




| Cut-Off 0 % | | | |
|---|---|---|---|
| Geological model | Mass t | Average Value FPA & FPB % | Material Content FPA & FPB t |
| Cover | 0.00 | — | 0.00 |
| FPA | 557 225 000 | 26.79 | 149 306 174.44 |
| FPB | 900 450 000 | 15.30 | 137 804 999.73 |
| Total | 1 457 675 000 | 19.70 | 287 111 174.17 |

| Cut-Off 20 % | | | |
|---|---|---|---|
| Geological model | Mass t | Average Value FPA & FPB % | Material Content FPA & FPB t |
| FPA | 549 247 500 | 27.88 | 153 103 149.43 |
| FPB | 113 967 000 | 22.88 | 26 070 976 |
| Total | 663 214 500 | 27.02 | 179 174 125.43 |

| Cut-Off 25 % | | | |
|---|---|---|---|
| Geological model | Mass t | Average Value FPA & FPB % | Material Content FPA & FPB t |
| FPA | 431 676 000 | 29.18 | 125 949 888.36 |
| FPB | 16 443 000 | 26.88 | 4 419 549.23 |
| Total | 448 119 000 | 29.09 | 130 369 437.59 |

| Cut-Off 30 % | | | |
|---|---|---|---|
| Geological model | Mass t | Average Value FPA & FPB % | Material Content FPA & FPB t |
| FPA | 148 716 000 | 31.80 | 47 287 558.35 |
| FPB | 1 728 000 | 31.25 | 539 945.35 |
| Total | 150 444 000 | 31.79 | 47 827 503.70 |

Figure 6 – Grade map of FPA and FPB (merged) for different cut off value with associated table of data.

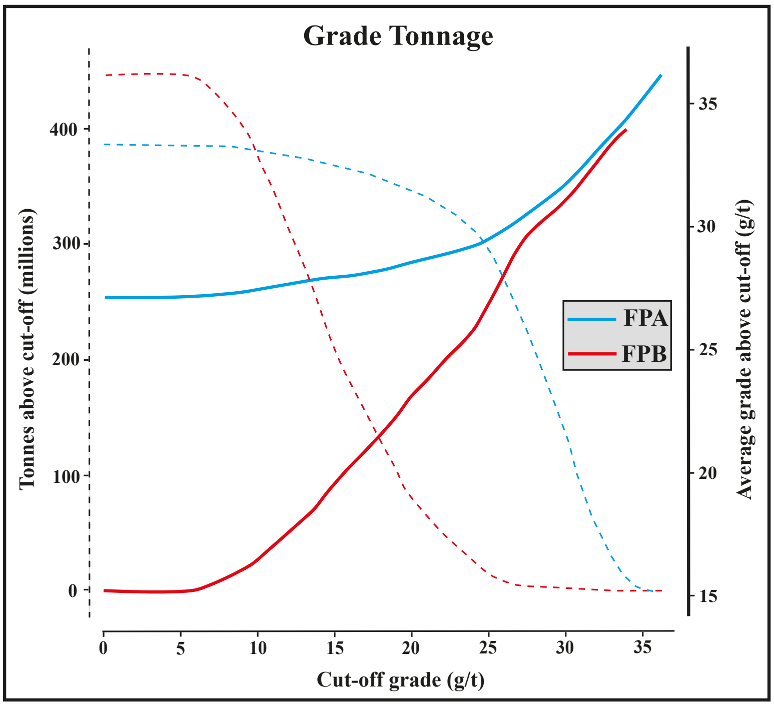



Figure 7 – Grade tonnage graphic depending on the cut off grade for FPA and FPB.

In order to determine the potential economic value of the deposit, it is necessary to quantify the quantities of phosphates that could hypothetically be extracted for a range of cut-off grade from 0 to the maximum grade values previously estimated with the variograms. The graph below shows the variation in the amount of phosphate and of the grade of the FPA and FPA layers in accordance with the cut-off. Even though the grade of the FPA layer is higher than that of the FPB one, it must be highlighted that for high values (> 25 g/t) the curves converge. Moreover, since the average grades for the whole FPB layer are globally around 10 g/t, it has a better tonnage than the FPA layer for cut-offs lower than 10 g/t.

In November 2020, the price for one ton of phosphate was $ 82.5.On the basis of the data coming from the previous graph, it is possible to draw the curve representing the profit as a function of the cut-off, as shown in the figure 8. Naturally, the direct consequence of a higher tonnage of the FPB layer that was discussed earlier, is that this layer will generate more profit for cut-offs lower than 10 g/t. The Table 1 shows the profits amounting to the volumes of phosphate depicted in the figure 6. Nevertheless, it is important to underline the fact that the costs of phosphate mining should be subtracted from the profits. Therefore, it seems reasonable to estimate that the final turnover is 100 to 1000 times lower than the gross profit.

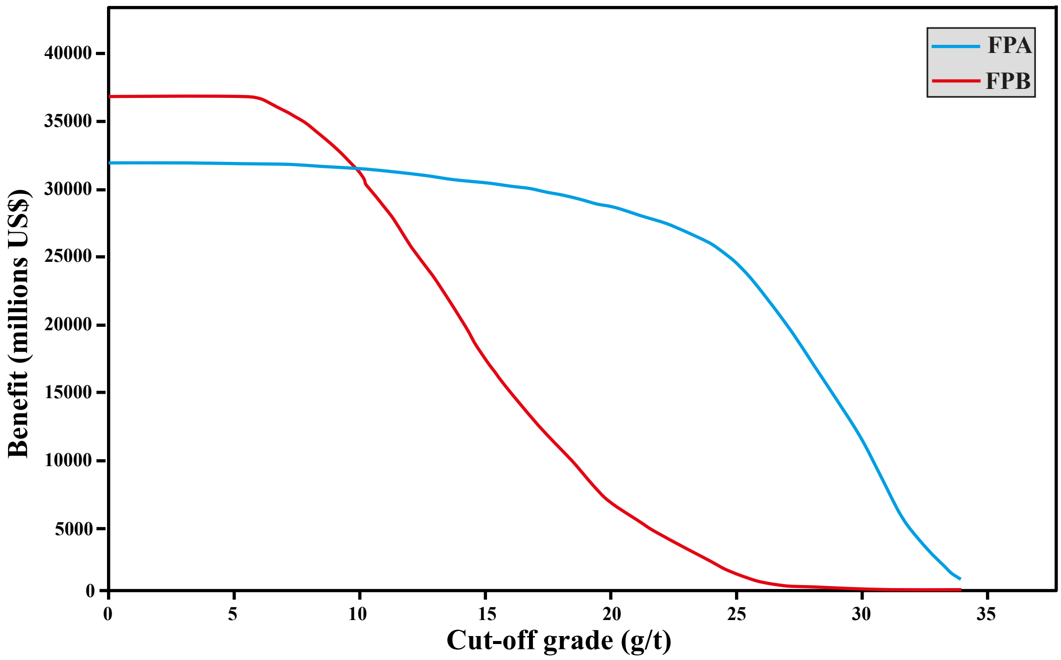



Figure 8 – Evolution of the benefit with cut-off grade value for FPA and FPB.

| Cut-off grade (g/t) | Profit FPA (millions US$) | Profit FPB (millions US$) |
|---|---|---|
| 0 | 31854,32 | 36807,13 |
| 20 | 28606,79 | 6580,86 |
| 25 | 24382,21 | 1249,462 |
| 30 | 11216,20 | 136,2075 |

Table 1 – Calculated profit of FPA and FPB layers depending on cut off grade.

# 6 Conclusion

In the end, the use of geostatistics tools is a genuine asset to the characterisation and modelling of the spatial repartition of natural resources. In the case of the phosphate deposit of Farim, the implicit modelling led to the conclusion that there is a cumulated profit with the FPA and FPB layers that vary approximately between $ 68,660 million and $ 11,352 million depending of the cut-off (varying between 0 and 30 g/t). Therefore, the study of a case like the deposit of Farim reveals to be a strategic study in terms of competitivity on the phosphate market, that is currently monopolised by Morocco.

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