**ASSESSING THE FEASIBILITY OF GEOSTATISTICAL APPROACHES TO CHARACTERIZE A STOCKPILE FROM AN IRON MINE OF IRAN**

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**Extended abstract**

Structural analysis of stockpiles variability is a crucial subject in stockpiles exploitations. Many environmental companies have developed and commercialized a proprietary technology to remediate tailings and stockpiles areas - harmless to both humans and the environment-resulting from mining operations. Recently modern processing and recovery methods and also increasing the metal demands with low grades lead to exploiting the remaining vast stockpiles as additional resources.

These large above ground stockpiles can be quantified, graded and valued to produce reliable modelling of processing costs and expected revenues. Of course it is necessary an adequate sampling of stockpiles for characterizing them, nevertheless some decisions have to be taken before sampling. Some pre-feasibility work can be done by knowing a numerical model of the deposit exploited and by simulating ore selection, haulage and piling. In this way, a simplified numerical model of the stockpile can be simulated, but it has to be validated even before sampling. An efficient control can be the study of grade variability, which results to be of mixed nature, partly natural and partly artificial.

In this study we are focused on two large stockpiles created from the open-pit Choghart iron mine during 7 years following the ore selection based on Phosphors and Iron grade: High Phosphorous (HP) stockpile received the ore with P grade higher than 0,6 %, unacceptable by the metallurgical plant, and Low Grade (LG) stockpile received the ore with Fe grade lower than 50 %.

Choghart Iron Mine has been a mining district since 1975s. Project was and still is to exploit a large Iron deposit located in the region of Bafgh, approximately 125 km south-east of the City of Yazd, Iran. Following the definition of Moor and Modabberi (2003), Choghart was initially a prominent black hill of iron ore measuring 800 x 300 m, standing 150 m above the surrounding plain at about 1257 m above sea level. This mine is an open pit operation, which includes the five stages of drilling, blasting, loading, hauling and crushing. Loading and transporting is done by a truck shovel system.

Following the pioneering work of Torab and Lehman (2006), the iron ore in this mine is a low sulphur type, 90% of the ore body is non-oxidized (magnetite ore) and more than 65% of the reserve is of a low phosphorous type. However, a huge amount of high grade-high phosphorous ore (an average grade greater than 0.6% phosphors) and low grade ore (an average grade less than 50% Iron) have been removed from the pit and stored in the HP and LG stockpiles, for possible future beneficiation.

The construction of these stockpiles was started since 1993 using trucks with the capacity of almost 35 tons and the materials were disposed into horizontal layers. One layer represents in average the piling of one month. Actually the two stockpiles are large in size, contain different ore grades and the material is cumbersome and costly to sample. Therefore, for the characterization of the stockpiles a numerical model has been set up based upon pre-existing information gathered from blast holes data. An estimated numerical block model of the deposit has been obtained by co-kriging. The estimated ore has been followed during the loading, transportation and dumping system of the Choghart mine. Finally a simplified numerical model of the stockpiles was resulted.

For the study are used blast holes data of five blocks (Block numbers: 478, 480, 482, 484 and 486) consisting of the low grade and high phosphorous ores in level 1140 of Choghart mine. They are samples regularized on a length of 10 m, drilled according to a regular pattern of 5x5 m. On fig.1 are shown the statistical distributions. Iron and Phosphors grades in the ore body are spatially structured and correlated as shown by the direct and cross variograms (Fig.2) where a linear corregionalisation model (nugget + exponential with range 20 m) has been fitted.

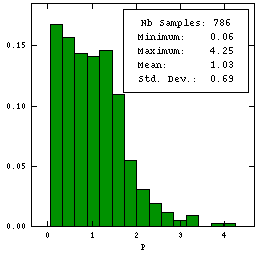
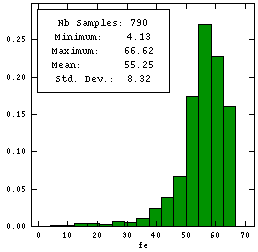


Figure 1. Histograms of Fe (left) and P (right) concentration (%) for data of blast holes in 5 blocks

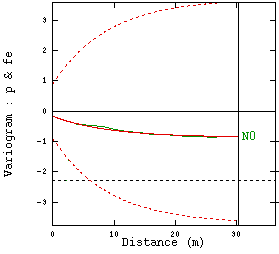
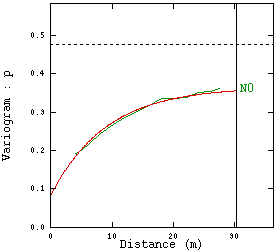
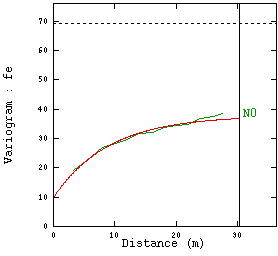


Figure 2. Experimental and cross variograms of Fe and P using blast holes of five blocks

Block size of estimated model was conditioned by the information available, in particular the height linked to the sample height: 10 \*2.5 \*1.4 m.

An important point for checking the coherence of the stockpile model is the study of the grades structural behaviour. As a matter of fact one stockpile is fed by a selected part of the deposit, so that it becomes important to verify the conditional spatial variability of estimated blocks. On fig.3 and 4 they are shown the direct and cross variograms of estimated blocks, conditionally to the selection criteria (LG, HP). The structural behaviour, with respect to the samples, is significantly modified by the three facts:

1. The support, which is now 3D and no more 1D; this lowers the dispersion and increases a little the ranges;
2. The estimation which decreases the dispersion according to the estimation variances;
3. The selection criteria, based on cut offs, which modifies means and variances, mostly of the variables to which the cut-off has been applied, and can modify also the ranges (Matheron 1982 “La destructuration des hautes teneurs”)

In fact, in the HP part of the deposit, the variogram sill of block estimated P and Fe grades are 28% lower than that of samples and in LG part of the deposit, the Fe grade has a variogram sill that is 30% lower with respect to the samples variogram and the P variogram has sill almost equal to the sill of samples.

For simulating the haulage, the elementary volume transported is linked to the truck capacity (35 tons), which means a volume about 1/3 of that of estimated blocks. Therefore, the elementary cell of stockpile model is a parallelepiped 1 m height, 3 m large and 4 m long. Finally, it is considered that the 3 cells of the stockpile fed by the same deposit block have all the same grade.

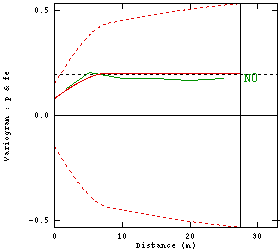
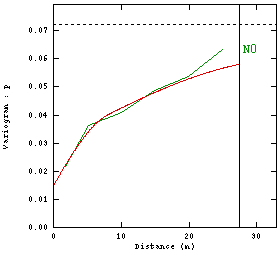
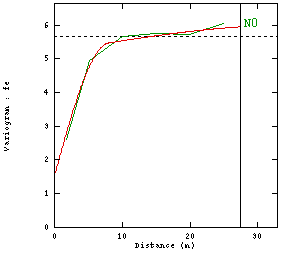


Figure 3. Structural analysis of HP part from estimated blocks for 5blocks

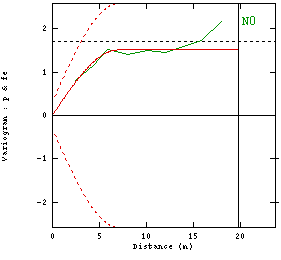
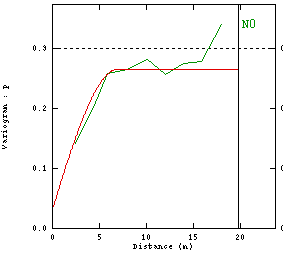
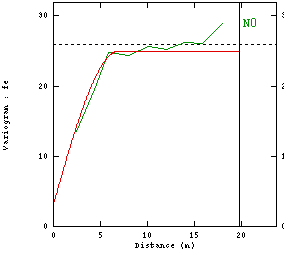


Figure 4. Structural analysis of LG part from estimated blocks for 5blocks

The simulation of stockpile construction considers that after completion of a line, a new line is piled and that when a level is filled, a new level is started. According to the constant height of excavated benches -10 meters- and also the constant height of each pile sequence -produced by trucks in the height of 1 meter- the estimation is implemented in 2-dimentions.

The numerical model of stockpiles by simulating the piling process from estimated data provides appropriate information to evaluate and compare piling design alternatives and to take any other decision. Nevertheless, a check is necessary before exploiting the piles numerical model. We propose to simply check the coherence of spatial variability of grades inside the stockpiles.

This should be linked to the piling simulation, which keeps mean and variance of block estimated grades of the selected portion of the deposit. Also the horizontal variability along the lines of discharge of trucks is kept, but with a range increasing of a couple of metres and with a differentiable behaviour near the origin due to the artificial homogeneity introduced by giving the same grade to three sequential cells. Almost nugget variability in the direction orthogonal to piling lines are generated (Table.1a and 1b).

On fig. 5 and 6 the expected spatial variability of cell grades in the stockpile are verified.

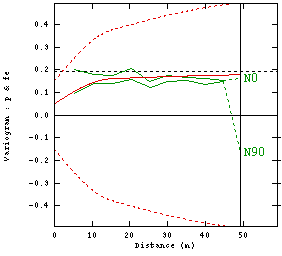
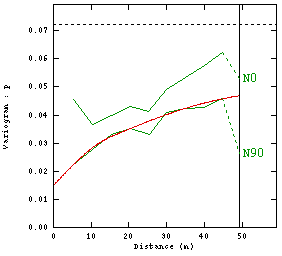
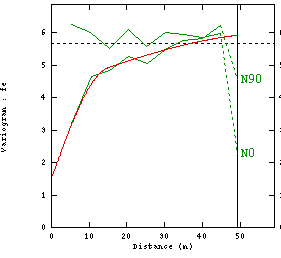


Figure 5. Structural analysis of simulated HP pile

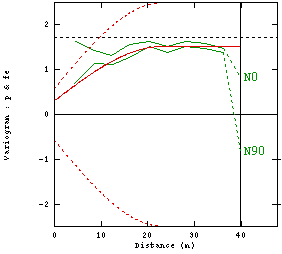
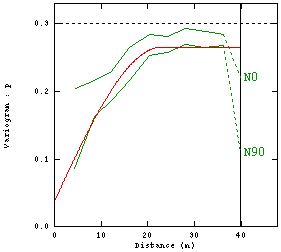
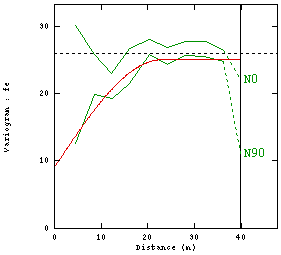


Figure 6. Structural analysis of simulated LG pile

By comparison of the structural analysis of estimated blocks (in HP and LG areas which were transported to the mentioned piles) and piles data, the main statistical parameters are constant as it is expected.

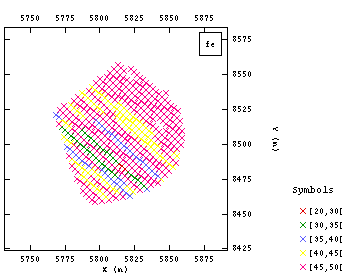
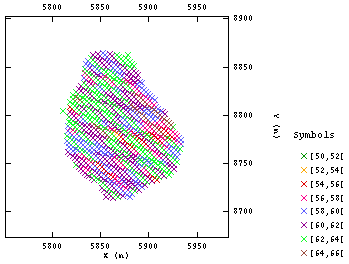
Table 1a: comparison of variogram parameters of structured component (spherical/spherical) in stockpiles and deposit blocks

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| hp | Model | Range(m) | Sill-fe | Sill-p | Sill Fe/P |
| Hp-blocks | Spherical | 8 | 3.7 | 0.005 | 0.06 |
| 35 | 0.8 | 0.028 | 0 |
| Hp-pile | Spherical | 15 | 2.8 | 0.008 | 0.1 |
| 60 | 1.7 | 0.025 | 0.03 |
| Lg-blocks | Spherical | 7 | 22 | 0.235 | 1.51 |
| Lg-pile | Spherical | 23 | 16 | 0.228 | 1.21 |

Table 1b: comparison of variogram parameters of nugget component in stockpiles and deposit blocks

|  |  |  |  |
| --- | --- | --- | --- |
| hp | Nugget fe(m) | Nugget P | NuggetFe/P |
| Hp-blocks | 1.5 | 0.15 | 0.12 |
| Hp-pile | 1.5 | 0.15 | 0.05 |
| Lg-blocks | 3 | 0.03 | 0 |
| Lg-pile | 9 | 0.037 | 0.3 |

In addition, variogram modelling of the pile data compared with the geostatistical parameters of the main deposit confirms that by simulating the pilling sequences exactly with the deposit data which were transported to the specific location in piles, it is easy to predict the variable characterization and also to estimate the spatial variability of piles without any extra sampling.



LG Pile

Fe

HP Pile

Fe

Figure 7. Map of Fe(%) variability in HP (left) and LG (right) stockpile obtained by simulation

This simulating methodology is simple, can be implemented in a short “macro” of excel, and may help especially when the stockpile sampling is not an appropriate choice.

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**Keywords**

Structural analysis, stockpile simulation

**References**

[1] Moor.F and Modabberi.S.(2003), Origin of Choghart Iron oxide deposit,Bafgh Mining district, central Iran: new isotopic and geochemical evidence, *Journal of Sciences, Islamic Republic of Iran,* University of Tehran 14(3): 259-269, ISSN 1016-1104

[2] Torab.F.M and Lehman B L.(2006), Iron oxide-apatite deposits of the Bafq district, central Iran: an overview from geology to mining,*World of Mining—Surface and Underground*58(6): 355-362.

[3] Matheron, George (1982b), La destructuration des hautes teneurs et le krigeage des indicatrices, Technical Report N.761, Centre de Géostatistique, Fontainebleau, France