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Exploitation planning in slate quarries by merging the recovery and quality indices

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ABSTRACT: The rational exploitation planning of slate quarries requires to forecast the *in situ* value of the material to be extracted, in order to include this value in the detailed production scheduling programme of the venture. Two components that relate the observable geological/technological attributes to the above considered *in situ* value are considered in this paper: the quality index of the plate and the recovery index of the exploitation. Once established these two indices by Correspondence Analysis and detected their spatial continuity by variography (auto and cross correlation), they are estimated in the exploitation volumes by Co-kriging. The estimated value of the combined index is the basis for further planning.

A case study, referring to the Valdeorras slate quarry, is presented for the purpose of illustrating the methodology. The estimated values are validated by using real data supplied by the exploitation experts of the quarry.

Key words: Slate quarry; Regionalised variable; Recovery index; Quality index; Correspondence Analysis; Variography; Co-kriging.

1- INTRODUCTION

When planning the exploitation of slate quarries, two components of the objective function should be taken into account: the costs of exploitation and the value of the material to be extracted. The first component, apart from other factors, depends on the exploitation recovery; the second component is related to the quality of the material to be extracted, for a given market situation. These two components - recovery and quality - are summarised by the methodology given in Pereira *et al.*, 92 and two indices are produced, each one of which reflecting a specific feature of the evaluation problem. In order to combine these two indices, conveying information from recovery to quality and conversely, a new step was added to the original methodology. This step consists of calculating the cross-variogram of the two indices by:

$$\gamma_{I_1 I_2}(h)=\frac{1}{2}E\{[I_1(x+h)-I_1(x)].[I_2(x+h)-I_2(x)]\}\ [1]$$

I_1 - Quality index
I_2 - Recovery index
x - co-ordinates
h - lag

and estimating the two indices in the exploitation units by Co-kriging (Journel & Hujbreghts, 1978), applying the system [2], where n is the number of samples and λ_{ij} are the Co-kriging weights

$$\begin{cases} \sum_{j}^{p}\lambda_{ij}\,\gamma_{jj'}(x_i,x_{i'})+\mu_{j'} = \gamma_{j'j0}(x_{i'},x_0), \\ \forall i'=1,\dots,n;\ \forall j',j=I_1,I_2 \\ \sum\lambda_{ij0} = 1 \qquad [2] \\ \sum_{i}^{n}\lambda_{ij}=0\quad \forall j=I_1,I_2;\ \forall j\neq j^0 \end{cases}$$

The proposed methodology, generalised to cope with the problems arising from the exploitation planning of slate quarries, was applied to the

Valdeorras quarry, located in Spain. The geological and geothecnical factors that influence the slate quality and exploitation conditions are of statigraphic, structural and metamorphic nature.

2 - DATA CAPTURE

The basic attributes on which the recovery and quality depend were scrutinised as given in table I:

Table I - Recovery and quality attributes to a slate exploitation

RECOVERY INDEX (I_1)	QUALITY INDEX (I_2)
nº fractures/m	Ultrametamorphised slate
nº Kink bands/m	Kink-bands
Alteration	Quartz - veins
RQD	Sand - laminations
	Oxidation
	Carbonates
	Multicrenulated slate
	Crenulation

These two sets of attributes were captured in 9 drill-holes, by counting the occurrence of their categories in 5m supports.
The classification was made by direct observation of the selected attributes on the core samples using video images and pericial information.

3-INDEX CALCULATION

By applying the equation (Pereira *et al.*, 1992),

$$f(i) = \frac{1}{\sqrt{\lambda . q}} \sum_{k=1}^{q} W(k) . \sum_{l=nc(k+1)+1}^{nc(k)} x(i,l) . p(l) \quad [3]$$

where

f(i) is the index of support *i*
λ is the eigenvalue associated with the discriminant axis
q is the number of attributes *k*
W(k) is the weight given to attribute *k*
nc(k) is the number of categories of attribute *k*
x(i,l) is the grade of membership of support *i* to category *l*
p(l) is the projection of category *l* onto the discriminant axis

The two indices were calculated on the basis of the attributes given in Table I. The system of weights *W(K)* and the attribute classes were modified interactively until a validation was reached against the expert opinion of the quarry management. Also, the archetypes of the poles of discrimination for both indices were established according to the experience of what is considered the extremes of recovery and quality by the quarry management.

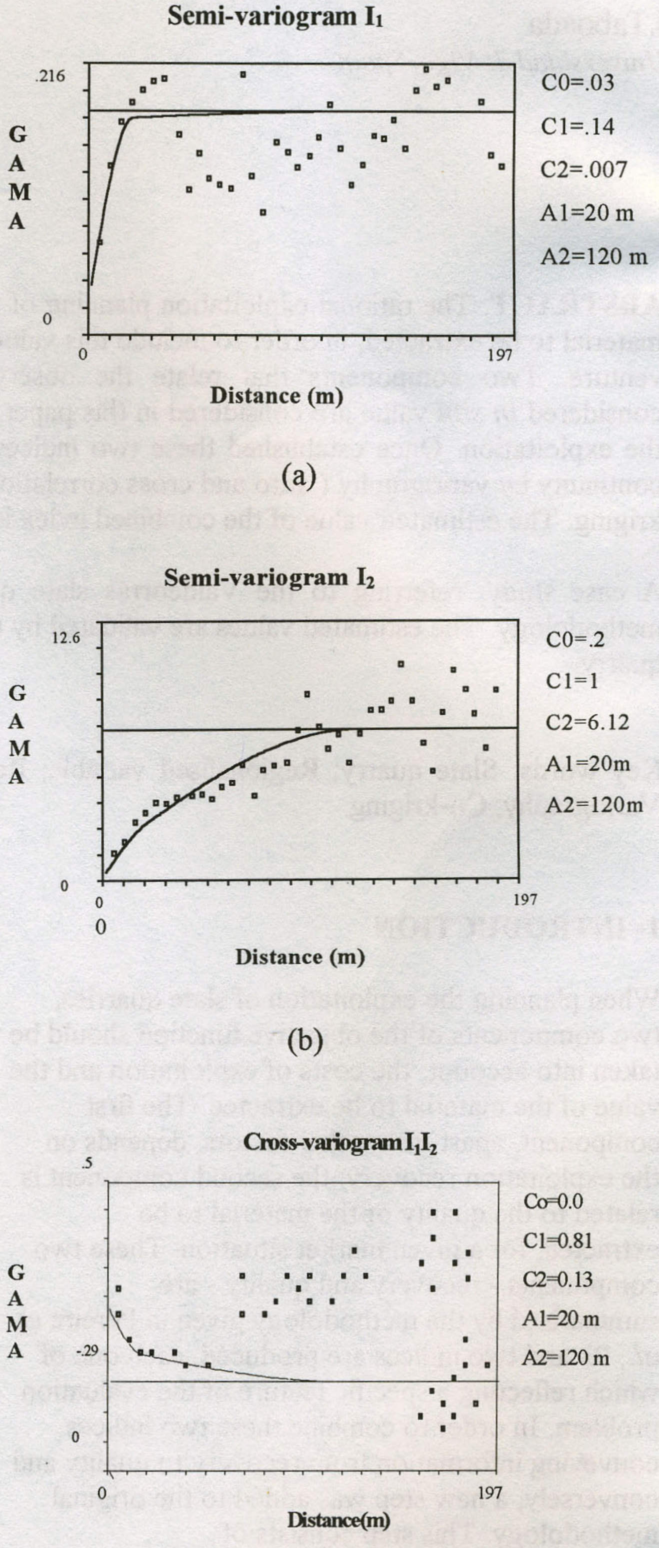


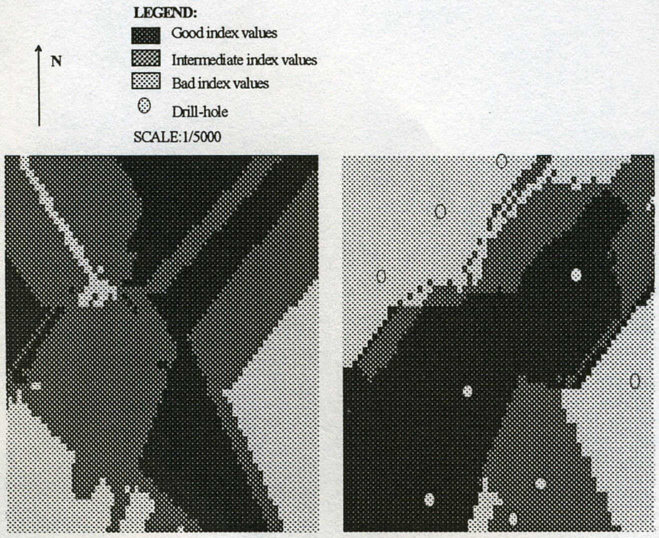
Fig.1 - (a) and(b) Semi-variograms for I_1 and I_2. (c) Cross-variogram of I_1I_2.

4 - ESTIMATION OF THE INDICES IN EXPLOITATION UNITS

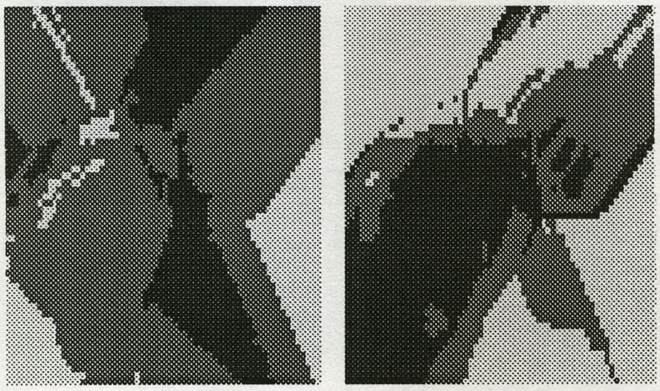
The omnidirectional variograms and cross-variogram of the two indices were calculated as shown in Fig.1:
Hence, the variogram parameters are summarised in Table II:

Table II - Theoretical spherical models parameters

	C_o	C_1	A_1	C_2	A_2
I_1	0.20	1.00	20m	6.120	120
I_2	0.03	0.14	20m	0.007	120
I_1I_2	0.00	0.18	20m	0.130	120



(a) I_1 and I_2 at level 1360m



(b) I_1 and I_2 at level 1315m

Fig.2 - Representation of the estimated values:

(a) Level at 1360m
(b) Level at 1315m

CONCLUSIONS

The proposed methodology allows the construction of two indices in slate quarries, each one of which reflects features of the material to be extracted: the recovery index is linked to the exploitation costs and the quality index summarises the value of the slate.

The two indices were calculated in the available drill-holes and their estimation in the production zone was performed by Co-kriging.

When the image of a working face is available, the recovery index can be calculate in the same support as drill-holes and the recovery index for that face can be inferred by the Co-kriging estimation procedures, permitting to guide the short term exploitation planning. This is the main advantage conveyed by the proposed Co-kriging method, since it is most possible to capture, in the face, the attribute in which the quality index is based.

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