Forecasting the Recovery in Dimensional Stones Exploitation by Using a Geomathematical Methodology

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Abstract

A methodology combining Data Analysis and geostatistics was established to cope with the problem of forecasting the recovery of dimensional stones exploitation. This methodology relies on the application of Correspondence analysis (Benzécri, 1980, Greenace, 1984) as a discrimination procedure for summarizing a variety of non-homogeneous attributes into a recovery index (I_1), which is treated by Geostatistics to provide a block model of the quarry (Pereira, et al, 1992).

The final results obtained by using I_1 show that some attributes exhibit an erratic behaviour that jeopardizes the index performance. This conclusion calls for an independent structural analysis of each characteristic before the construction of the summary index.

According to the contiguity arising from the analysis of the independent variography of each variable category used in I_1, categories and correspondent limits were redefined and the same methodology was applied, giving rise to a more contiguous recovery index (I_2). The validation of this new recovery index with real values shows that kriged values of I_2 are more accurate.

A case study regarding marble quarries is presented to illustrate the methodology and a framework for generalization is given, permitting to use different kinds of attributes.

Key-words: Marble Quarry; Regionalized Variable; Recovery Index; Correspondence Analysis; Variography; Kriging.

Introduction

Even though some geostatistical studies on the modelling of fractures in rock masses were published (v.g. Miller, 1979, Soulié, 1986, Chilés, 1989[1], Chilés, 1989[2]), the application of the models as a basis for the economical evaluation and planning of dimensional stones quarries exploitation is an open issue.

In particular, the major problem faced by marble exploitation planning is the lack of an objective criterion to optimize the economical production recovery.

In a first approach to this problem (1), a novel methodology, combining iteratively Multivariate Data Analysis and Geostatistics, was developed, aiming at the establishment of a quantitative index (I_1), related to the value of the material being exploited, that can be used as a basis for exploitation planning. The result obtained by comparing the estimated values of I_1 with real validation data, show that the methodology could be improved if some erratic components were suppressed from the index construction.

In a second approach (2), a preliminary structural analysis of the attribute's categories that intervene in I_1 was carried out,leading to a redefinition of classes and suppression of random attributes. The same methodology used for I_1 was then applied on the new set of attribute's classes, giving rise to a new index I_2, which shows a better match with real values.

1 - Establishment of I_1

1.1 - METHODOLOGY

Giving a non overlapping window over the working faces of a quarry, fracture attributes (nominal, ordinal, numerical and boolean characteristics), are systematically recorded in a regular support, according to the data gathering procedure described in Pereira *et al*, 1992.

in A.G. Fabbri et J.J. Royer (eds), 3rd CODATA Conference on Geomathematics and Geostatistics. Sci. de la Terre, Sér. Inf., Nancy, 1994, **32**, 371-381

Numerical data are split into classes and all attributes are encoded into approximately equal frequency disjunctive categories (Nanache, 1973), and in some cases, variables are assigned to a fuzzy grade of membership category.

The general encoding scheme that includes all data types under a homogeneous format is represented in fig.1

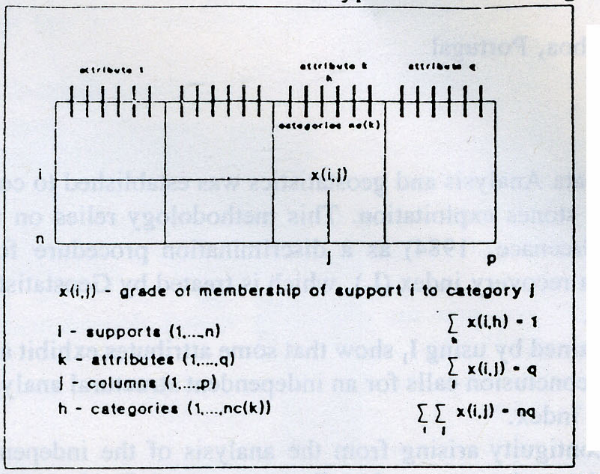


Fig.1 - Basic experimental matrix of supports vs. attributes encoded by a fuzzy disjunctive scheme.

Given q attributes related to marble recovery, a basic matrix X, containing the values $x(i,j)$, is calculated by the fraction of the total observations in a single support s (row i in fig.1.) that falls in the category h of attribute k (column j in fig.1).

After summarizing the categorical data in the matrix X, the two poles of the index scale were identified by the analysis of the semantics of each attribute from the point of view of the recovery, choosing the worse attribute's categories set to characterize the **BAD** pole and the more favorable classes to define the **GOOD** pole (Fig.2).

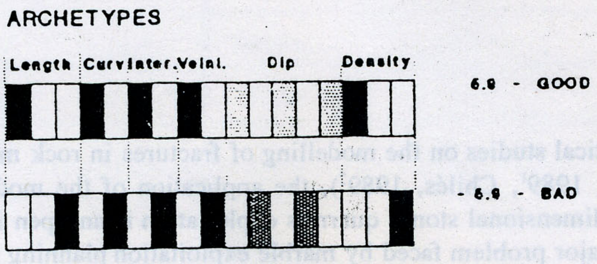


Fig.2 - archetypes of marble recovery poles, for index I_1

The supplementary projection of the basic experimental matrix X onto the axis given by the Correspondence Analysis algorithm applied as a discriminating technique to the two poles matrix (Pereira, 1988, Pereira *et al*, 1992), provides a recovery index prone to be analyzed by variography and estimated by kriging in the surrounding exploitation area.

1.2 - CASE STUDY

The available study area is located in Alto Alentejo, in the Estremoz marble massif, near Borba (Gonçalves, 1971, Martins, 1981).

Data were captured from 17 working faces in two different levels, in a quarry called Encostinha, with an area of $300m^2$. The average recovery of this quarry is about 40%, and commercial blocks exploited in its superficial levels are 1.5 x 1.5 x 1.0 m in size.

The data capture procedure is illustrated in Fig.3, where each fracture is assigned to the support that contains its middle point.

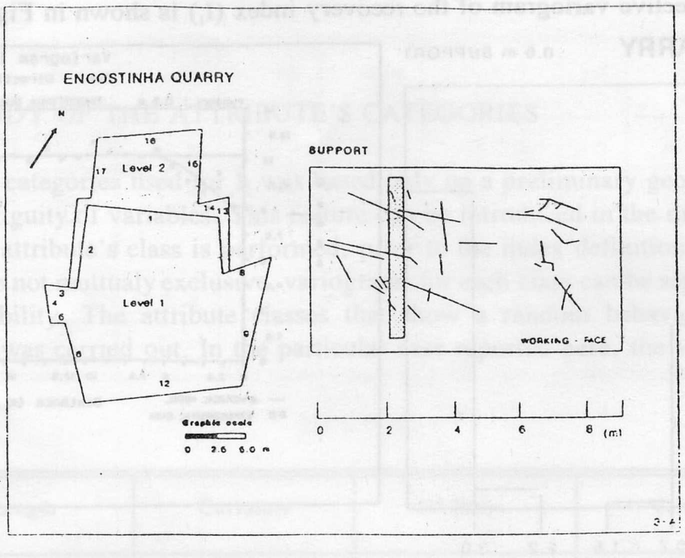


Fig.3 - Example of data capture for assigning observations to supports

The attributes chosen for characterizing each fracture are **Length, Curvature, Number of Intersections, Presence/Absence of Veinlets, Dip, Density of Fractures**, and the procedure for assignment of fractures to attribute categories (Table I) can be visualized on Fig.4

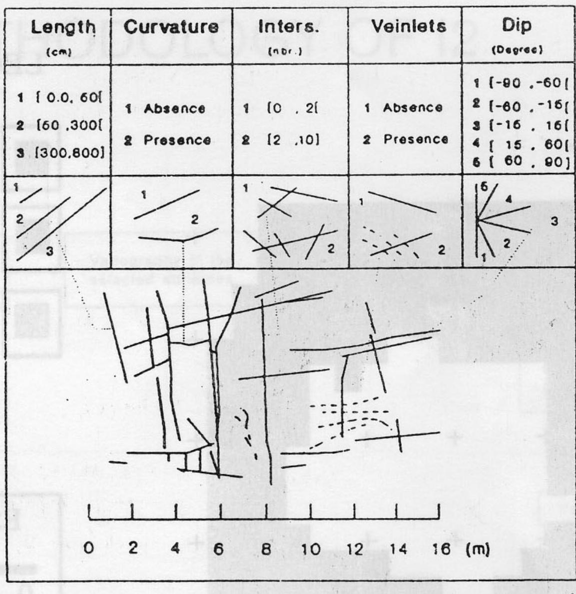


Fig.4 - Example of assignment of fractures to attribute categories

class / variable	Length	Curvature	N°inter.	Veinlets	Dip	Density
1	0 - 50	Absence	0 - 2	Absence	-90 - -60	0 - 10
2	50 - 300	Presence	2 - 10	Presence	-60 - -15	10 - 30
3	300 800	------------	------------	------------	-15 - 15	30 - 100
4	------------	------------	------------	------------	15 - 60	------------
5	------------	------------	------------	------------	60 -90	------------

Table I

The relative frequency of each attribute category is calculated for each support (matrix X), and applying Correspondent Analysis as a discrimination technique for the above defined two poles (**GOOD** and **BAD**), the values of each recovery index vectors were obtained by the supplementary projection of each

The histogram and respective variogram of the recovery index (I_i) is shown in Fig.5.

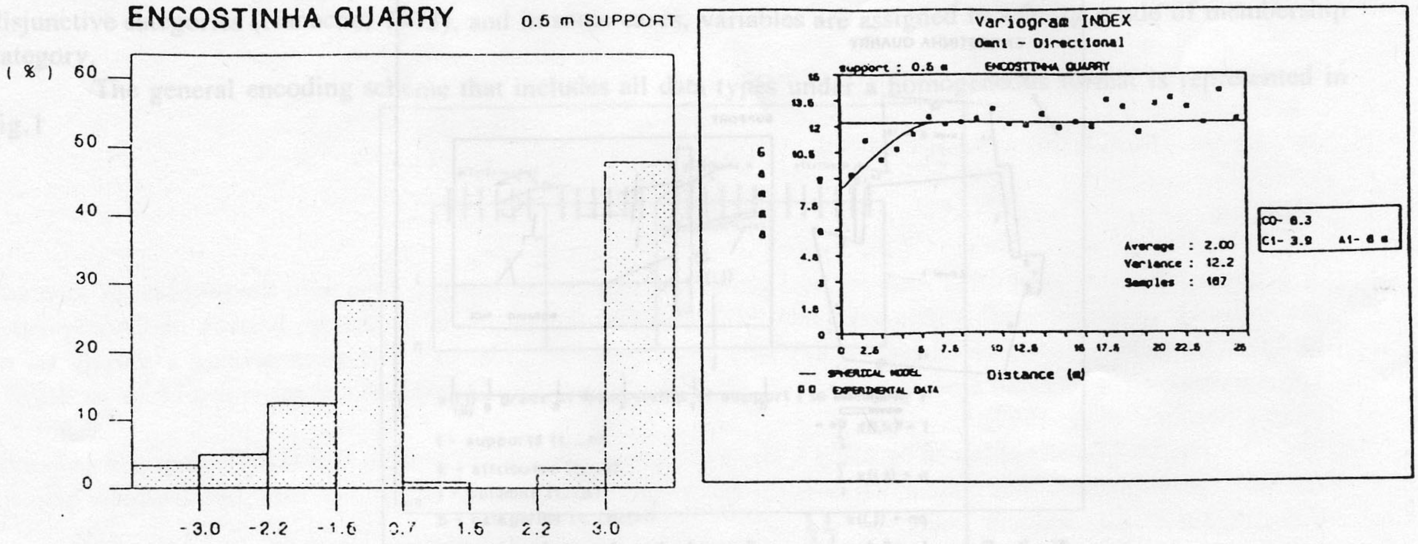
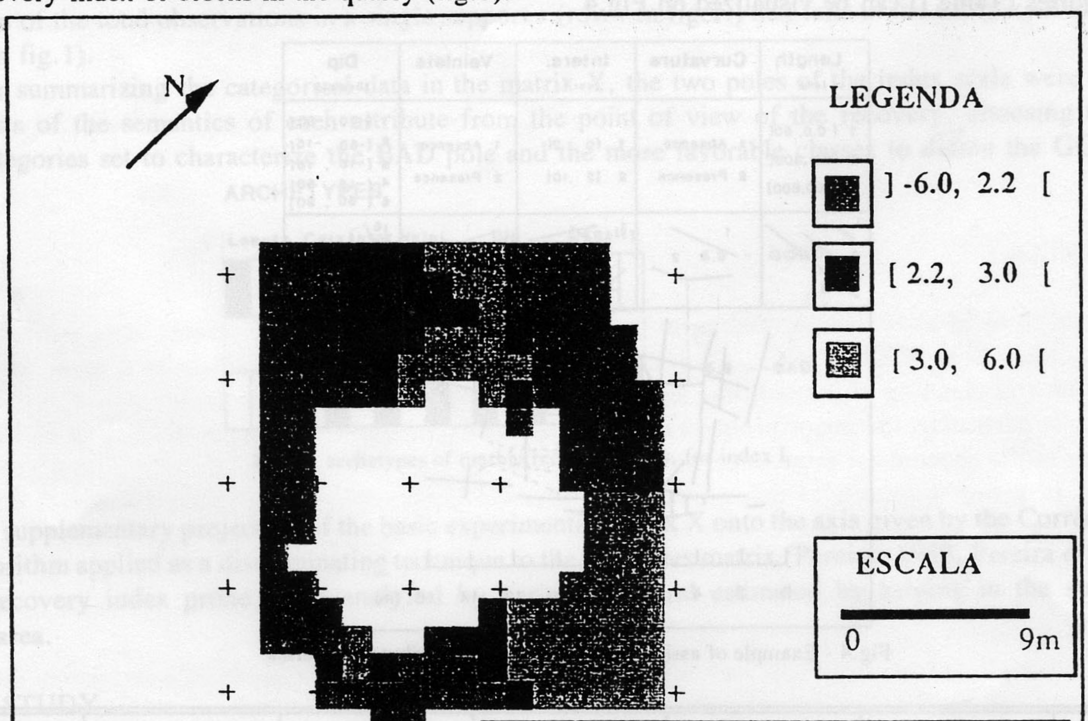


Fig.5 - Histogram and variogram of the recovery index I_i, for the 0.5m. support.

Once fitted the theoretical model to be used in kriging (1.5x1.5 block), a kriged map was produced, derived from the recovery index of blocks in the quarry (fig.6).



I_i	% of real values	% of estimated values
Good	40.0	17.7
Interm.	33.3	31.7
Bad	26.7	50.6

Fig.6 - I_i kriged blocks (1.5 x 1.5 m).

2 - Establishment of I_2

2.1 - STRUCTURAL STUDY OF THE ATTRIBUTE'S CATEGORIES

The selection of attribute's categories used for I_1 was based only on a preliminary geological study which does not account for the spatial contiguity of variables. This feature can be introduced in the methodology if an exploratory structural analysis of each attribute's class is performed, prior to the index definition (Fig.7).

Since attributes are not muttualy exclusive, variograms for each class can be separately calculated, revealing their contiguity and variability. The attribute classes that show a random behaviour were suppressed or the redefinition of their limits was carried out. In the particular case reported here, the variables and classes retained are given in Table II.

Class variable	Length	Curvature	N° Inters.	Veinlets	Density
1	0 - 300 cm	Absence	0 - 2	Absence	0 - 10%
2	> 300 cm	Presence	2 - 10	Presence	> 10%

Table II

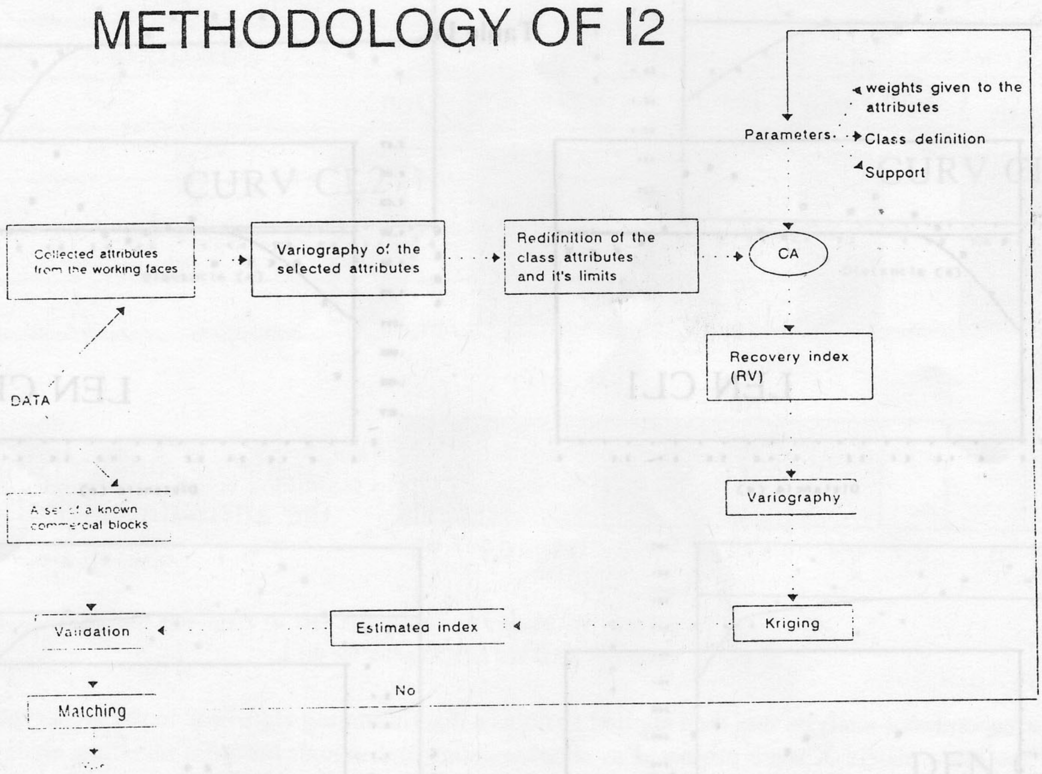


Fig.7 - Metodology applied on I_2 definition

The experimental variograms of the variables defined in Table II are shown in Fig.8. The parameters of the spherical models fitted to the experimental variograms are given in Table III.In Table IV it can be seen that on average 46% of the variability is still retained within the support.

	Dip Cl1	Dip Cl2	Len Cl1	len Cl2	Vein Cl1	Vein Cl2	Int Cl1	Int Cl2	Curv Cl1	Curv Cl2	Den Cl1	Den Cl2
C_o	0.10	0.30	0.80	0.90	0.10	1.20	1.30	0.10	1.50	0.40	0.14	0.10
C_1	0.50	1.17	0.77	0.67	0.24	1.74	1.09	0.17	1.05	0.76	0.03	0.01
C_2	0.10										0.02	0.02
a_1	2	2	2	2.5	2	2	2.5	2	2	2	1	1
a_2	8										4	

Table III

	Dip cl1	Dip Cl2	Len Cl1	Len Cl2	Vein Cl1	Vein Cl2	Int Cl1	Int Cl2	Curv CL1	Curv Cl2	Den Cl1	Den Cl2
Variance	0.7	1.47	1.57	1.57	0.34	2.94	2.39	0.27	2.55	1.16	0.19	0.13
% retained within the support	14.3	20.4	50.9	57.3	29.85	40.8	54.4	37.0	58.8	34.5	74.0	76.9

Table IV

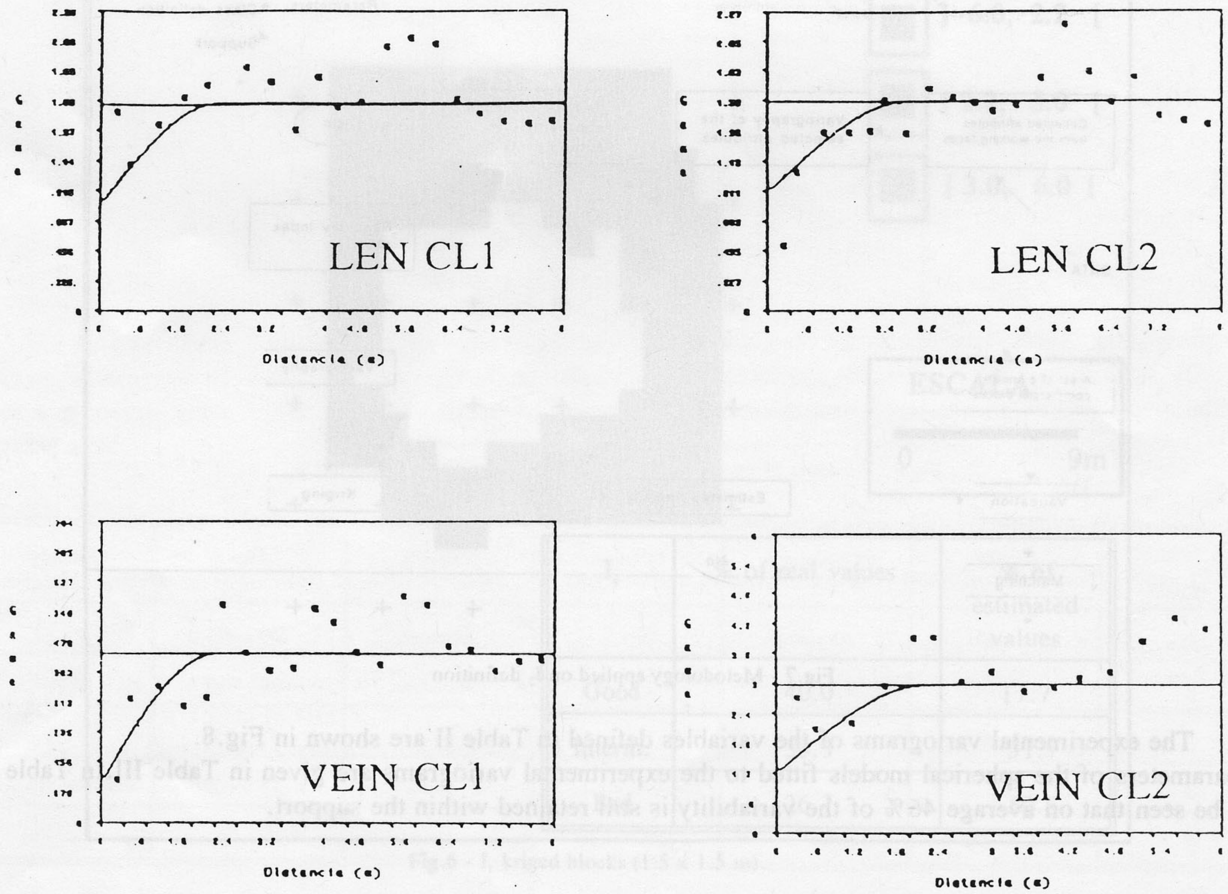


Fig.8 - Variogram of the attributes.

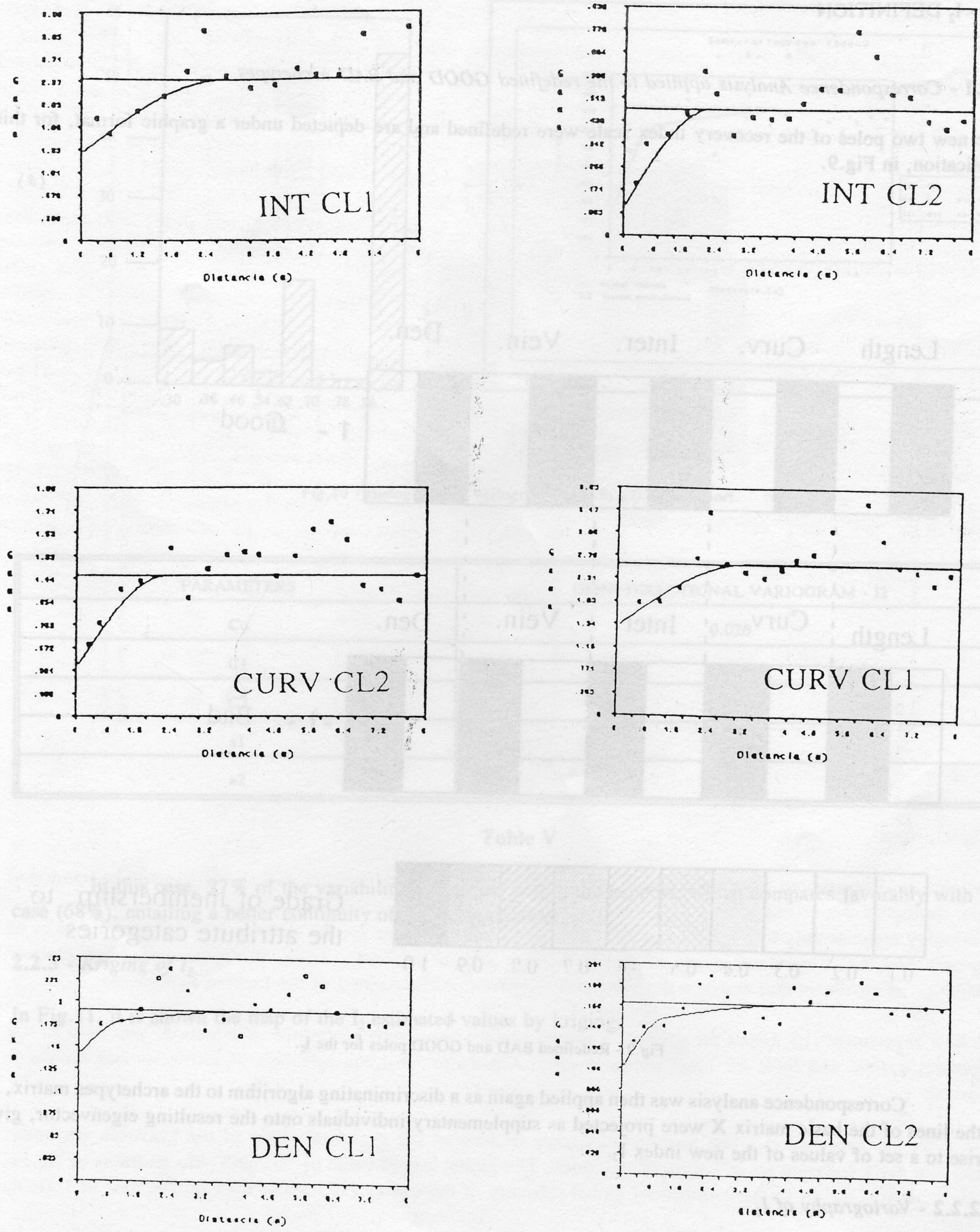


Fig.8 - Variograms of the attributes (cont.).

2.2 - I_2 DEFINITION

2.2.1 - *Correspondence Analysis applied to the redefined GOOD and BAD archetypes*

The new two poles of the recovery index scale were redefined and are depicted under a graphic format, for this application, in Fig.9.

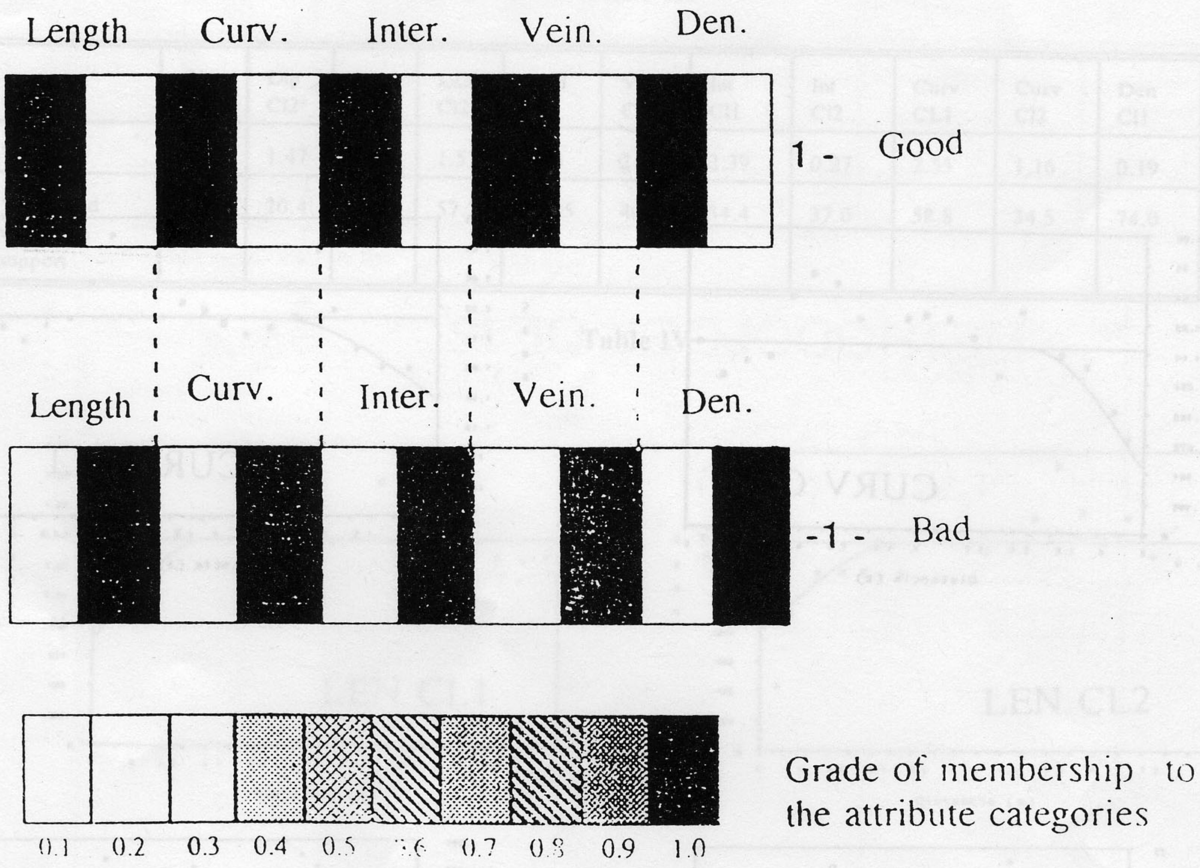


Fig.9 - Redefined BAD and GOOD poles for the I_2.

Correspondence analysis was then applied again as a discriminating algorithm to the archetypes matrix, and the lines of the basic matrix X were projected as supplementary individuals onto the resulting eigenvector, giving rise to a set of values of the new index I_2.

2.2.2 - *Variography of I_2*

In Fig.10, the histogram and variogram of I_2 is shown. The parameters of the fitted spherical scheme are given in Table V.

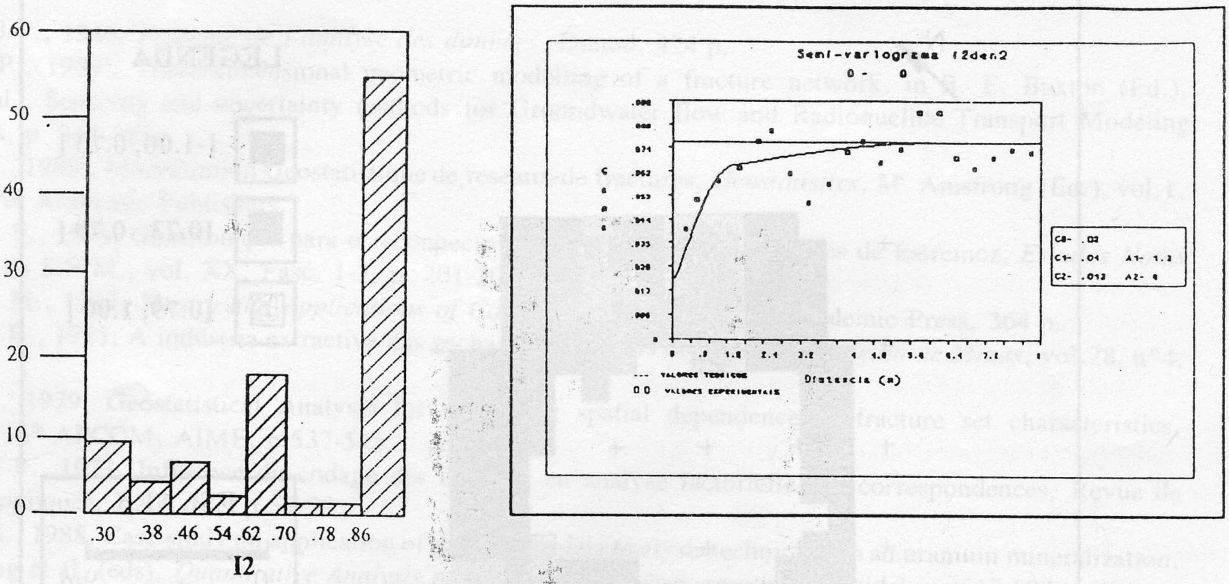


Fig.10 - Histogram and variogram for I_2 in a 0.5m. support.

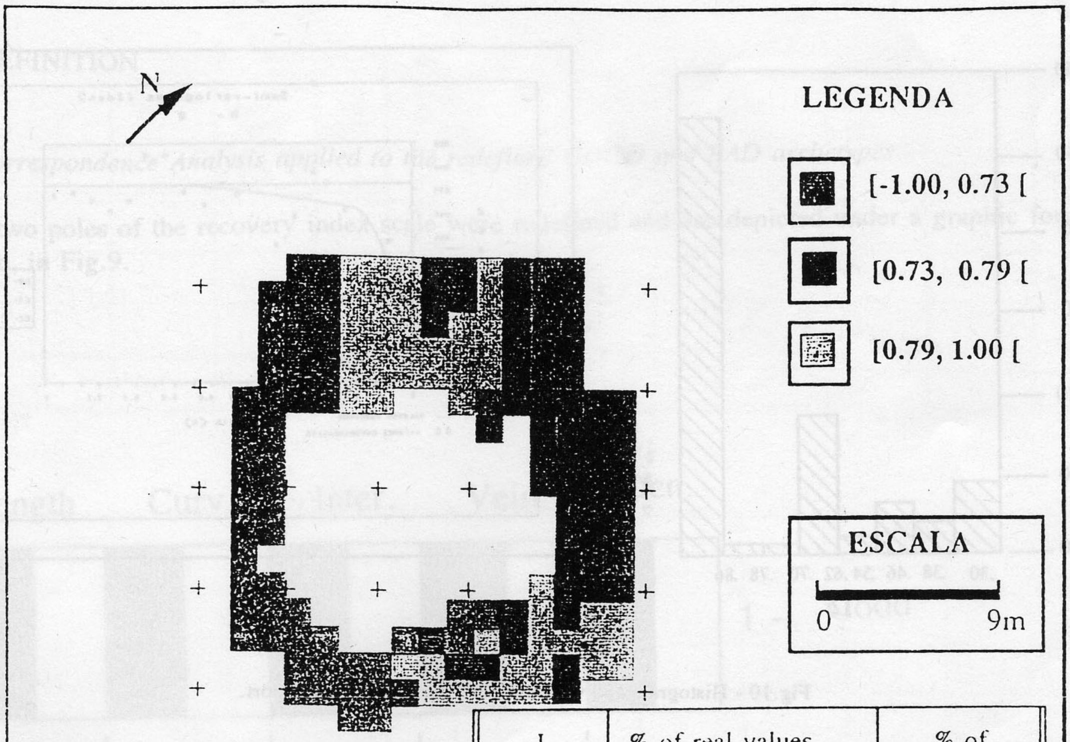
PARAMETERS	OMNI-DIRECTIONAL VARIOGRAM - I2
Co	0.020
C1	0.040
C2	0.013
a1	1.200 m
a2	6.000 m

Table V

In this case, 27% of the variability is retained within the support, which compares favorably with the I_1 case (68%), entailing a better continuity of this new variable.

2.2.3 - *Kriging of I_2*

In Fig.11, it is shown the map of the I_2 estimated values by kriging.



I_2	% of real values	% of estimated values
Good	40.0	30.3
Interm.	33.3	26.5
Bad	26.7	43.2

Fig.11 - I_2 - kriged blocks (1.5 x 1.5 m).

3 - Conclusions

I. The case study presented illustrates how to articulate multivariate data analysis and geostatistics in an integrated system aiming at the estimation of a recovery index for marble quarries. The approach behind the proposed methodology assumes only that a certain set of recovery related attributes can be measured in the working faces of the quarry and that a certain amount of real validation data is available. Then, the system searches for one combination of attributes that matches the validation data, within the context of the inputed hypotheses.

II. A first experiment (I_1), based on attribute's classes arising only from geological information, was used to test the general system and look for local improvements, namely in what the selection of attributes and classes is concerned.

III. In a second approach (I_2), the methodology takes in account the structural study of the available attributes, leading to a more coherent set of values of the index. The global kriged value of "GOOD" blocks (table of fig.11) for the index I_2 is nearer to the commercial global recovery of the quarry (30 - 40%) than for the case of I_1 (table of fig.6).

Acknowledgments

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