THE APPLICATION OF GEOSTATISTICS TO THE DESCRIPTION OF OIL RESERVOIRS

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ABSTRACT. A systematic methodology aiming at the optimal estimation of pertinent variables for the oil reservoirs description and characterization phase was developed. The application of this methodology, relying mainly on geostatistics and multivariate data analysis techniques, allows to develop accurate reservoir description models, improving the simulation results of fluids flow and leading to useful production planning predictions. A case study regarding an extensively recognized oil reservoir is presented, to illustrate the articulation of data processing techniques.

1. INTRODUCTION

The first step of the description phase of an oil field development project includes an extensive critical assessment of all geological, petrophysical and production data.

Based on the interrelations linking these data and on their spatial distribution, a reservoir description model, assigning realistic values of pertinent physical properties (porosity, permeability, fluids saturation, etc.) to grid blocks, must be produced. The performance of fluids flow simulation programs relies strongly on the initial parameters provided by this reservoir description model.

In order to establish such a model, a systematic methodology, based mainly on geostatistics and data analysis techniques, was developed to cope with specific characteristics of petroleum variables. In particular, when designing such a methodology, data from different sources and scales must be integrated (Fig.1), geological qualitative information must be taken into account,

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in P. A. Dowd et J. J. Royer (eds.), 2nd CODATA Conference on Geomathematics and Geostatistics. Sci. de la Terre, Sér. Inf., Nancy, 1992, 31, 155 - 167.

geometrical problems must be solved, heterogeneities related to the internal architecture of the reservoir must be detected and mapped (cf. Da Costa e Silva, 1985), non-stationary estimation techniques must be applied, prediction of tensorial variables like permeability must be performed. These requirements call for important adjustments in the standard data processing techniques, mainly in what concerns transitive kriging of indicator data for boundaries estimation and treatment of non-additive tensorial variables by correspondence analysis.

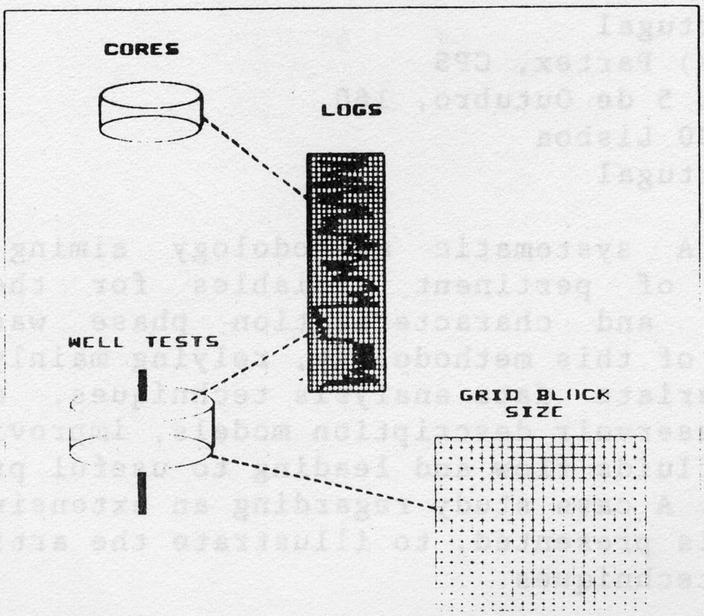

Fig.1 - Data for modelling purposes

In order to test the proposed methodology and establish the guidelines for the required adjustments, a data driven approach was adopted. Since a reliable and representative data set is available, this approach allows to check the articulation of the processing techniques on a real case, providing a global illustration of their application.

This work is part of a research project granted by the EEC Hydrocarbons Commission, the objective of which is to design an integrated software package for modelling oil reservoirs, allowing for the inclusion of geostatistics in the industrial practice.

2. ARTICULATION OF DATA PROCESSING TECHNIQUES

The articulation of a variety of data processing techniques, encompassing geostatistics and multivariate statistics, was performed, in order to provide a reliable reservoir description model.

Fig. 2 shows the information flow from data to objectives and the network of operators required to process the available information, according to the proposed methodology.

The main steps of this methodology are the following:

ZONATION	- produces groups of samples which are homogeneous with respect to a similarity criterium (Pereira and Soares, 1989).
STRUCTURAL ANALYSIS	- produces variogram models which account for spatial correlation.
GEOSTATICAL ESTIMATION AND SIMULATION	- produces estimated/simulated maps of the relevant variables to be used in oil in place reserve calculations or in the initialization of production planning models.

Once defined the logical links connecting the processing techniques, an extensive testing on real data was performed, aiming at the selection of the appropriate techniques for each situation. Furthermore, adjustments to operational conditions were accomplished and new approaches to cope with non-trivial issues were developed.

3. PRACTICAL APPLICATIONS AND RESULTS: EXAMPLES OF CASE STUDIES

3.1 Geostatistical estimation of reservoir properties

The basic problem addressed in this example is how to extend the data available in a few wells (cores, log analysis or test results) to a field basis, providing the input for the initialization of reservoir simulation models at the nodes of an appropriate grid (cf. Fig. 1).

Given that, in most cases, relevant variables associated to oil reservoir (e.g. thicknesses, top and bottom elevation, porosity, etc.) display a non-stationary behaviour, the geostistical estimation of those variables was performed using the universal kriging approach (UK). In fact, in a previous study concerning the same field (Pereira et al., 1989), the conclusion was reached that UK is the most performant technique whenever a reliable structural analysis can be performed. This is the case of this field, where 182 wells are available and variograms reproduce the main geological, petrophysical and geometrical features of the reservoir.

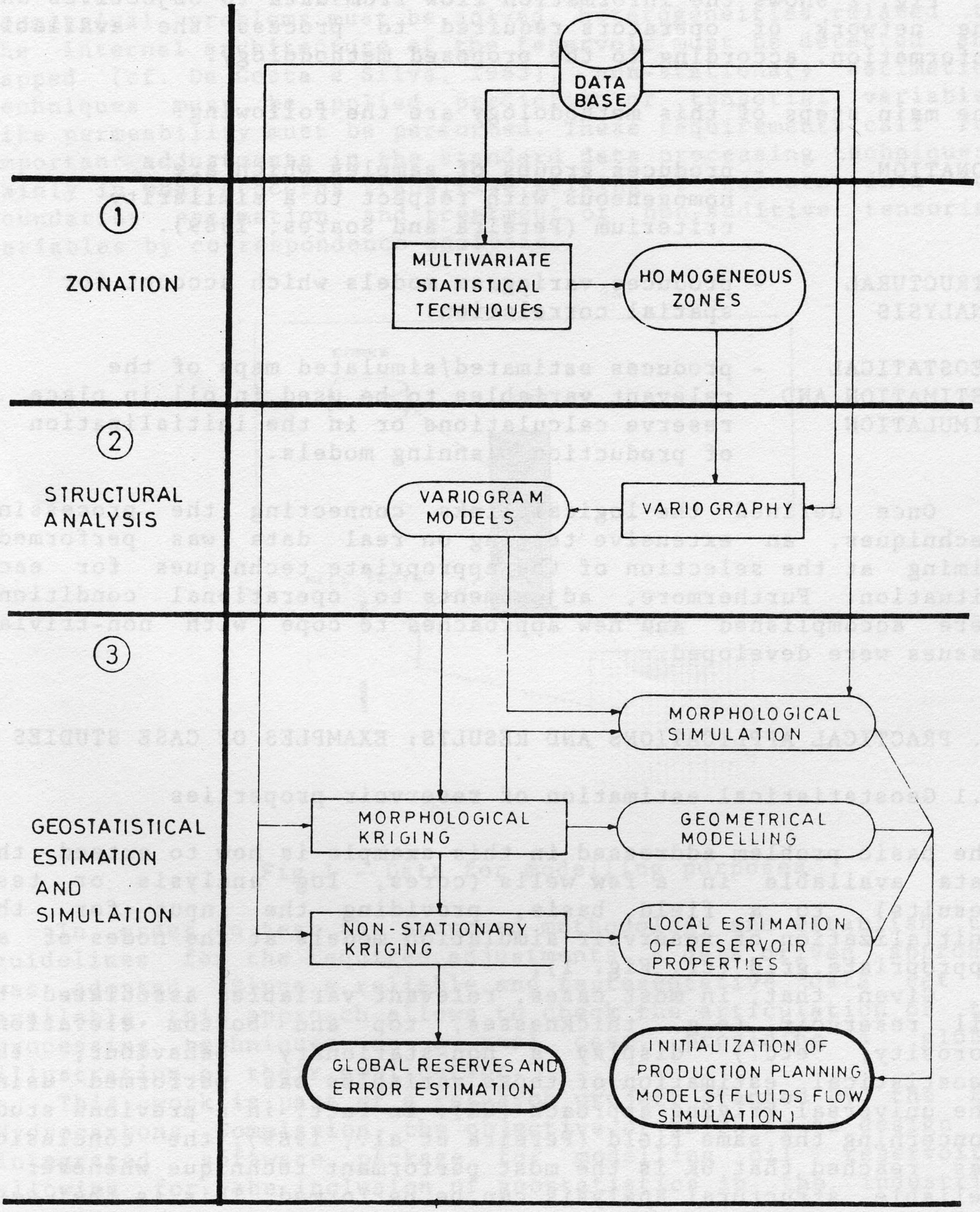

Fig. 2 - Articulation of data processing techniques

In the framework of the UK approach, the Regionalized Variable $Z(x)$ is split into terms: $Z(x) = m(x) + Y(x)$. The raw variogram for the variable thickness $Z(x)$ in a certain zone of the reservoir (zone B) is given in Fig. 3. Having fitted a polynomial drift $m(x)$ by trend surface analysis, residuals $Y(x)$ were computed and the corresponding variogram is shown in Fig. 4.

The underlying variogram $\gamma_t(h)$, which is the required structural function for the UK system, was derived by the trial and error procedure described in Fig. 5, assuming a linear model $\gamma_t(h) = W|h|$ and using as validation criteria the following statistics:

$$ME = 1/N\ \Sigma(Z^* - Z) \qquad [1]$$

$$ME = 1/N\ \Sigma\ [(Z^* - Z)/\sigma k]^2 \qquad [2]$$

where N is the number of data points, σk is the kriging standard deviation and * denotes an estimated value.

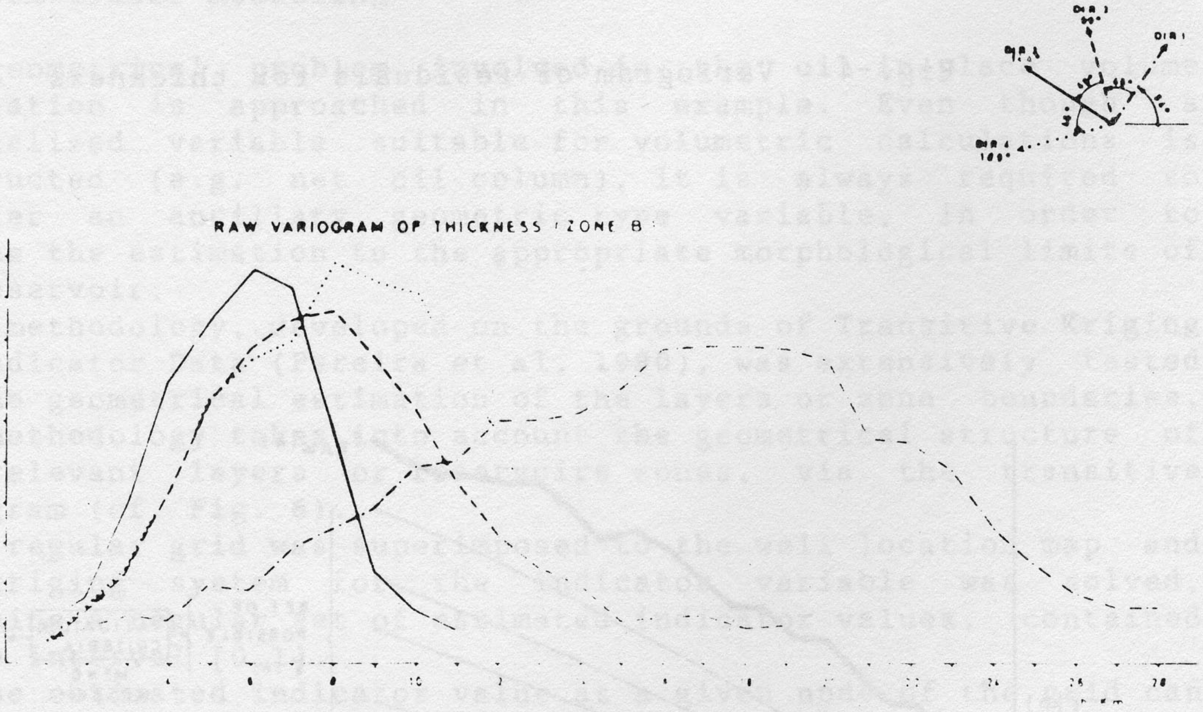

Fig. 3 - Raw variogram for thickness

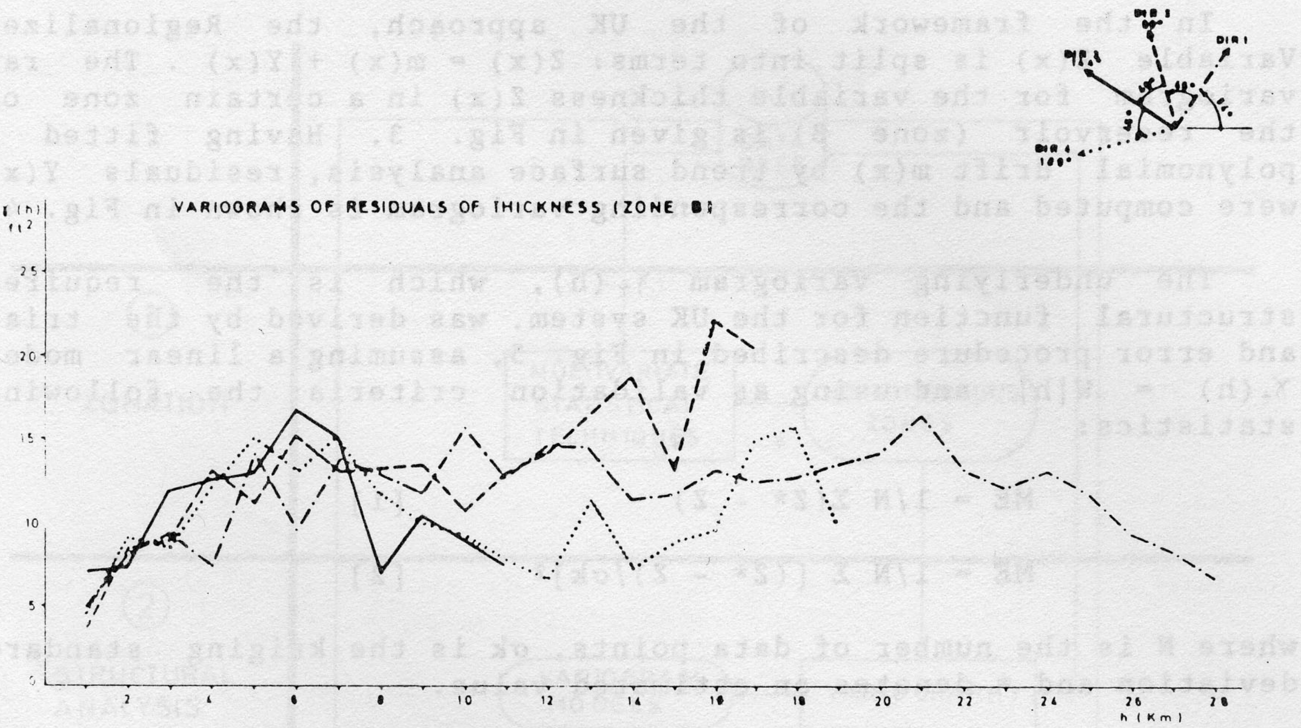

Fig. 4 - Variogram of residuals for thickness

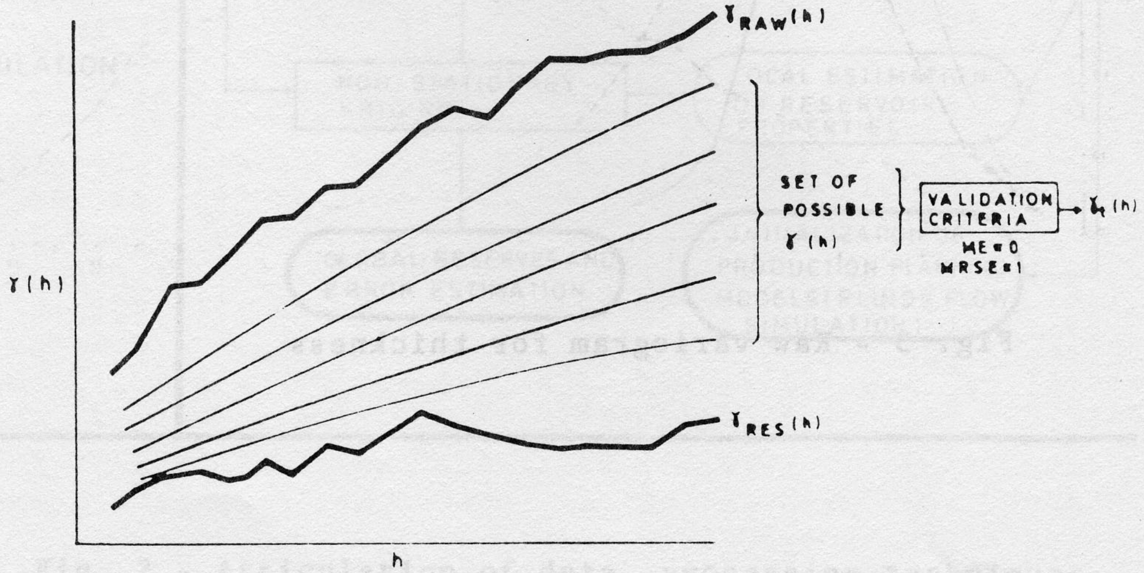

Fig. 5 - Scheme for selection of the underlying variogram model

For the selected zone, results of the validation tests are show in table I, being the upper and lower bound of parameter W derived by inspection of Fig. 3 and 4.

Parameter W			Validation Criteria	
Lower bound	Upper bound	Selected	ME	MRSE
.009	.014	.012	.188	.999

Table I - Results of the validation criteria for the identification of parameter W of the underlying variogram.

Using the underlying variogram $\gamma_t(h) = .012|h|$, the UK system provides the estimation of the variable and the corresponding error.

3.2 Geometrical Modelling

The geometrical problem involved in the oil-in-place volume calculation is approached in this example. Even though a regionalized variable suitable for volumetric calculations is constructed (e.g. net oil column), it is always required to consider an ancillary geometric type variable, in order to confine the estimation to the appropriate morphological limits of the reservoir.

A methodology, developed on the grounds of Transitive Kriging of Indicator Data (Pereira et al, 1990), was extensively tested on the geometrical estimation of the layers or zone boundaries. This methodology takes into account the geometrical structure of the relevant layers or reservoirs zones, via the transitive variogram (cf. Fig. 6).

A regular grid was superimposed to the well location map and the kriging system for the indicator variable was solved, producing a regular set of estimated indicator values, contained in the interval [0,1].

The estimated indicator value at a given node of the grid can be interpreted as the probability that such point belongs to oil. This probability map was then converted into a binary map for the dense grid of points, according to the procedure described in Pereira et al., 1990. Fig. 7 shows the boundaries of the oil zone.

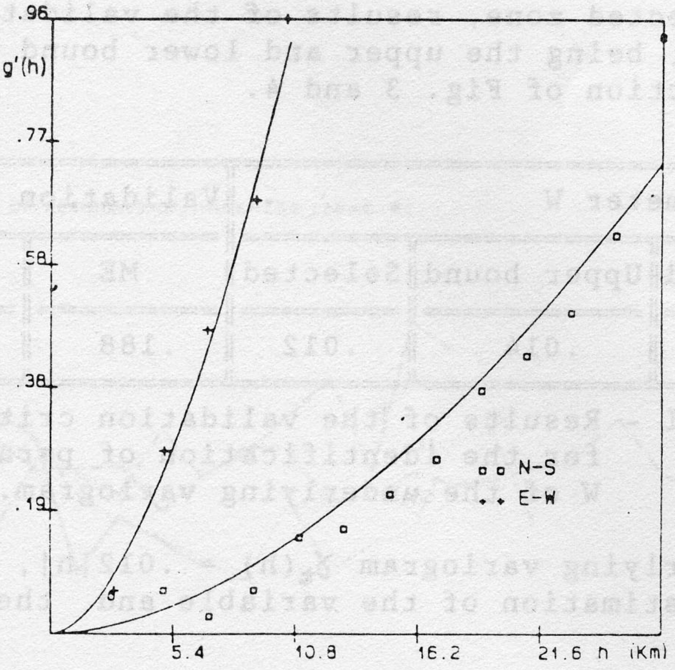

Fig. 6 - Transitive variogram of the indicator variable

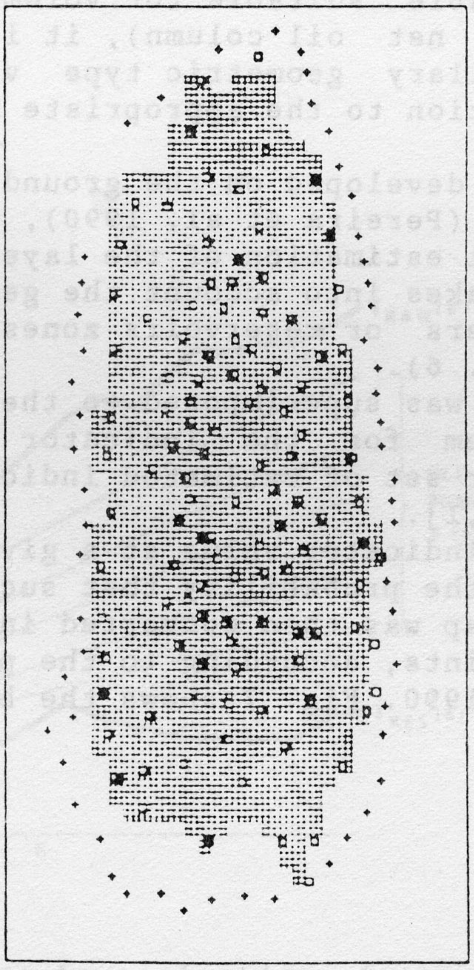

Fig. 7 - Boundary of the oil zone

3.3 Reserves Calculation

The geostatistical methodology was adapted to the specific characteristics of the oil-in-place volume evaluation by constructing a regionalized variable, denoted "net oil column", given by:

$$O = h\,\phi\,(1 - SW)$$

where h is the layer thickness
ϕ is the porosity
SW is water saturation

The 3-D geometrical problem was split into two parts:

- .An ordinary 2-D geostatistical estimation of the variable net oil column at the nodes of a grid
- .A geometrical geostatistical estimation of the oil limits in a plane (closure area)

Once defined the boundary of the zone considered as oil (cf. 3.2), it is required to estimate the average net oil column inside that boundary. For this purpose, the variogram shown in Fig. 8 was computed. The fitted model to EW direction is spherical scheme of nugget effect C0=1 ft^2, sill C=7 ft^2 and range a=6 Km. For the NS direction, a drift of degree k=1 was found.

The cross validation criteria (cf. [1], [2]) calculated for this fit are the following:

ME = 0.101
MSRE = 1.055

Using as input the net oil column values of the wells contained in the boundary and the fitted variogram model, the UK system was solved for calculating the average net oil column, giving rise to the following results:

average net oil column = 6.31 ft
relative error (95% confidence) = 4.34%

Combining these results with the area estimation, the final value of the volume and error was found:

oil-in-place volume = 1.545 x 10 9 STB
relative error (95% confidence) = 4.43%

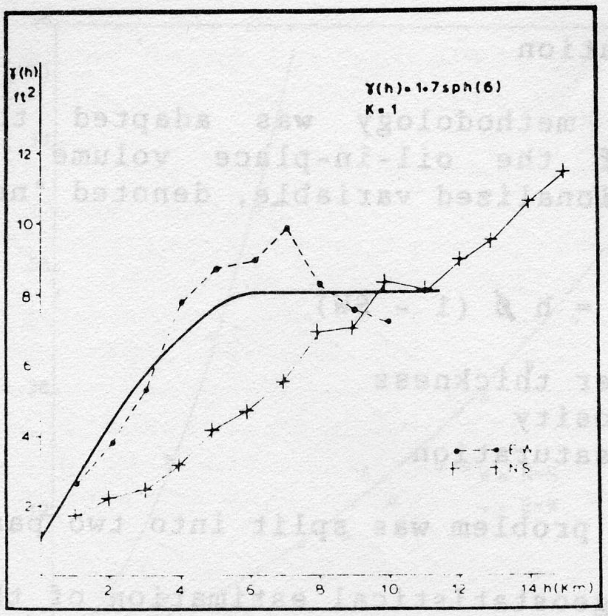

Fig. 8 - Variogram of the variable net oil column

3.4 Permeability predictive model

For permeability estimation, a particular approach was devised to cope with the specific characteristics of this variable, namely its tensorial and non-additive features.

In fact, direct estimation of permeability based on analytical relationships cannot satisfactorily account for the entire useful range of this complex variable. Prediction of extreme values is a major matter of concern, specially for defining flow barriers.

The proposed approach assumes that a set of "explicative" variables and qualitative attributes (e.g. porosity, clay content, dolomite content, limestone matrix, water saturation), available in log records for 182 wells, can be related to permeability. The set of measured permeabilities, derived from core data, is only available in 80 wells, being the purpose of the method to predict permeability in the remaining wells.

The idea behind the method is to perform some sort of "qualitative regression" of permeability classes against the explicative variables and attributes, which are also encoded in disjunctive categories, by applying the supplementary projection properties of Correspondence Analysis. The factorial axes are based only on the explicative variables, and supplementary projections of the available permeability data on those axes define zones in the factorial space, which are characteristic of each permeability class. Hence, the set of available permeability measures are classified according to the zone they belong in the factorial space, which was constructed only on the grounds of the explicative variables.

Now, given a vector of explicative variables assigned to a point where no permeability is available, the supplementary projections of this point into the above defined factorial axes can be obtained and, consequently, the point is assigned to a certain zone of the factorial space.

So, the permeability of that point may be estimated as some statistical central location measure of the distribution of real data contained in the pertinent zone of the factorial space.

This methodology is illustrated by the results of a test conducted for a given well, where real permeability values are recorded. Profiles of real and estimated K values are given in Fig. 9. A good agreement is obtained, ever for the extremes, specially using the mode as estimator.

4. CONCLUSIONS

A variety of procedures, algorithms and processing techniques have been articulated in a coherent methodology encompassing the main critical steps of Reservoir Description. Data processing techniques were adjusted and tested for the specific characteristics of oil variables and systematic case studies were conducted, in order to illustrate the modelling methodology.

The general achievements described in this paper are summarized in the the sequel:

-Variographic techniques were adapted to the non-stationary behaviour of most petroleum variables, accounting for geological and petrophysical information.

-The problem of reserves calculation was solved according to the argument that morphological issues play an important role in the estimation procedure. In fact, the estimation of the net oil column at the nodes of the appropriate grid depends on closure area definition, which is a geometrical problem, calling for boundaries optimal design.

-Regarding the geometrical modelling issue, it was proposed a method, relying on transitive kriging, to cope with the problem of spatial extension of a set of samples, which were previously assigned to a certain type by a indicator function. The advantage of this method with respect to any "blind" interpolation procedure is that uncertainty levels are associated with the estimation boundaries, since the spatial structure of the available geometrical information is taken into account.

-For the particular case of permeability, given its tensorial nature and the usual paucity of data, a special "qualitative regression" approach was developed, relying on supplementary projections in Correspondence Analysis.

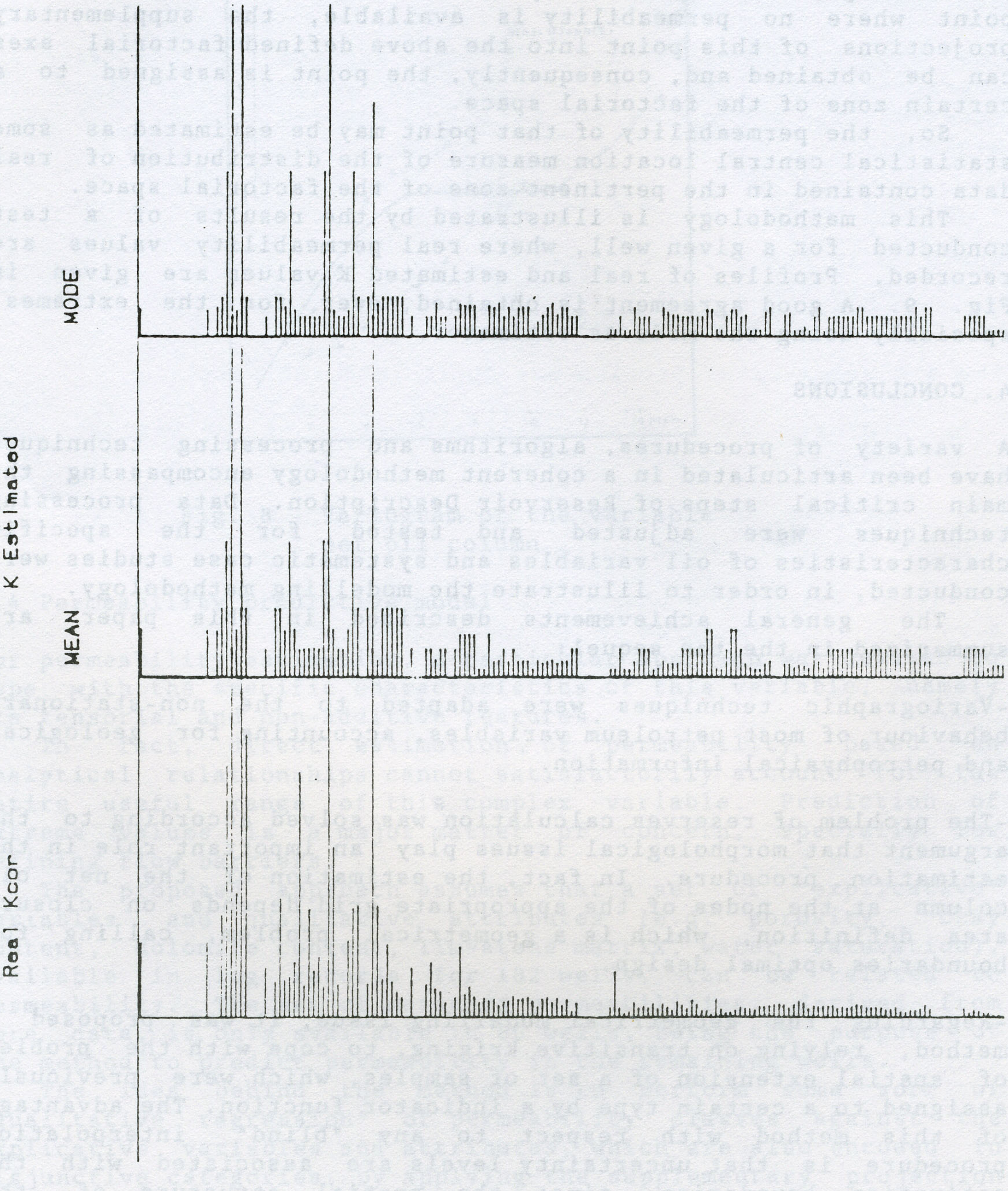

Fig. 9 - Comparison of real and estimated permeabilities (K) in a testing well

5. ACKNOWLEDGEMENTS

This research programme was made possible by a grant of the EEC Hydrocarbons Commission.

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