Velocity Models Stratigraphically Conditionated for Time-to-depth Conversion

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Abstract

This paper presents a geostatistical-based methodology to obtain an average velocity field constrained by stratigraphic correlations in order to be used for time-to-depth conversion. Such methodology is applied to a Campos Basin offshore field, Brazil.

Introduction

Time-to-depth conversion (T-D) is certainly a problem as old as seismic which solution is very important for well locations and reserves estimates. Unfortunately, this is not a simple problem and the choice for the best methodology depends on the available data, on the geology and on the goals of the conversion. In an exploration context, a T-D conversion technique, that somehow guarantees the horizons geometry, is desirable. The prediction capacity of the objective's real depth, although important, is secondary. It is not the same in the development context, mainly due to the horizontal wells, for which it is necessary a very good depth prediction. Errors of 1% in the average velocity, that is not considered nonsense, may impact a typical turbiditic reservoir depth of brazilian coast with an error over 20 m, which is enough to compromise a horizontal well location.

An efficient and cheap methodology that has becoming popular is to generate a normal incidence velocity field (V_{NI}) from the average velocities standardized on wells, using the velocity analysis data (velan) as drift on kriging with external drift according to Lopes *et al.* (2000).

Kriging with external drift (KED)

Kriging is a linear estimate which weights are computed as a function of a spatial covariance model of data with two constraints on the estimate error - null average and minimum variance. In the kriging system with external drift, the spatial variability of secondary variable, Z_2, is assumed to be related to the primary variable local drift, Z_1, in such a way that the primary variable expected value is non-stationary and is given as:

$$E[Z_1(U)] = a_0 + a_1 Z_2(U) \tag{1}$$

The coefficient values, a_0 and a_1 are estimated by regression of Z_1 e Z_2 at the same position. Their estimates, a_0* and a_1* are used to estimate the primary data residuals.

$$Z_1(u_\alpha) - \left[a_0^* + a_1^* Z_2(u_\alpha)\right]$$

These two steps are combined into a universal kriging system which estimator of primary variable is:

$$Z_1^*(u) = \sum_{\alpha=1}^{n} \lambda_\alpha Z_1(u_\alpha) \tag{2}$$

The kriging weights, $\lambda_\alpha(u)$, are the linear system solution (Deutsch & Journel, 1996):

$$\begin{cases} \sum_{\beta=1}^{n_1} \lambda_\beta C_R(u_\beta - u_\alpha) + \mu_1 + \mu_2 Z_2(u_\alpha) = C_R(u - u_\alpha) & \alpha = 1,\ldots,n_1 \\ \sum_{\beta=1}^{n_1} \lambda_\beta = 1 \\ \sum_{\beta=1}^{n_1} \lambda_\beta Z_2(u_\beta) = Z_2(u) \end{cases} \tag{3}$$

The Lagrange parameters μ are associated with the weights and C_R refers to the residual covariance $Z_1 - Z_2$. The secondary variable magnitude is not important, only the derived shape provided at the n_1 primary data locations. The maps of variable Z_1 are similar to those of Z_2, because they are related by equation (3).

Case History

The goal of this study is an offshore field in Campos Basin with 53 wells drilled, 20 of them with sonic logs. However, the reservoir bottom and a regional Eocene horizon are strongly marked on density logs by a deflection, so that it can be tied to the seismic data very precisely, even though in the wells without sonic logs, by correlating this density deflection with positive picks of these two reflectors. This correlation was validated from the synthetic logs derived from the 20 wells with sonic logs.

In the T-D 3D seismic conversion program in study it was not possible to use the velan's data and the ordinary kriging results of well's average velocities were not robust, so it was necessary to develop a new methodology to generate a velocity field confident to T-D conversion.

It was observed that the main unsuccessful factor in building an average velocity field from the kriging well velocities was related to an inadequate corregionalization model, that due to a regular grid, was not able to model the average velocity trend, generating unreliable results in the structured areas. Then it was necessary to estimate a velocity field through a kriging algorithm that take into account, during the estimating process, the field stratigraphy and structural, operating along lines of correlation previously defined, based on the seismic interpretation, as summarized into Figure 1. However that the correlation lines of an average velocity field does not have any relation with geological structure, so that any estimate process that intends to honour the geological correlation must be done with interval velocity. With such restriction, only the 20 wells with sonic logs were used to build this velocity field. As in the wells the sonic logs were not recorded in all the drilled interval, is was necessary to use, in each of them, a unique interval velocity value in the depth comprised between the Eocene and the Sea bottom, corresponding to the average velocity of this interval. In the same way, the water velocity was used in the corresponding interval. Sonic data converted into interval velocity together with seismic horizons (Sea bottom, Eocene and Reservoir bottom) were used as guide surfaces. The correlation lines were defined according to the depositional history.

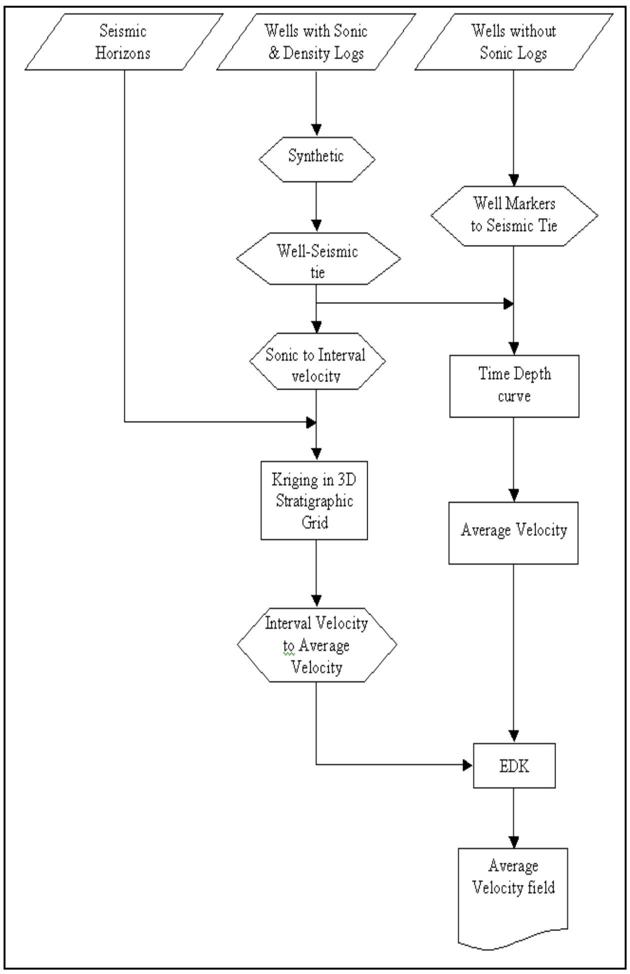

Figure 1 - Methodology developed to generate a stratigraphic conditioned average velocity field.

On the second level that corresponds to the reservoir itself, the correlation lines were defined parallel to Eocene, based on the depositional model of the reservoir – turbidites deposited over an erosional surface. The Eocene is a regional horizon that can be considered sub-parallel to the reservoir top. On the third level, the correlation surfaces were defined as proportional surfaces. It is the thickest interval to be converted, but with less available information because the variable to be estimated is not an interval velocity but an average velocity. The choice for the proportional correlation can be understand as the choice for the average. For the fourth level it was imposed a constant velocity equal 1500 m/s.

The variograms were computed along the correlation lines, previously defined, and the models fitted were a Gauss with 1200 m range in XY and 80 ms in time direction at Level 1, a Gauss with 1200 m in X, 800 m in Y and 80 ms in time direction at Level 2 and a Gauss with 2000 m in XY and 80 ms in time direction in Level 3.

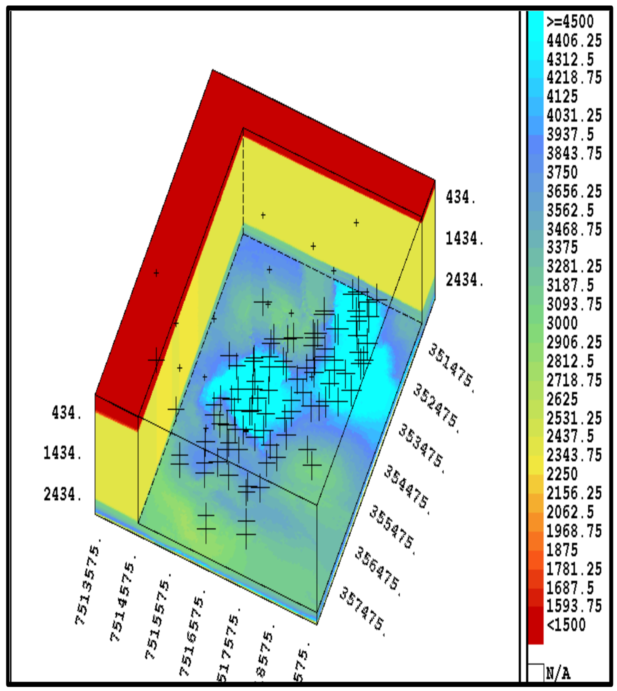

Figure 2 - Interval velocity field estimated from the 20 wells with sonic logs, by OK in a stratigraphic grid.

The interval velocity field estimated can be seen in Figure 2. It can be observed that the interest area is structured with the carbonates below the reservoir – high velocity – higher at the centre, giving a geological consistency. However, this velocity field can be optimised once it was used only 20 wells in its estimative, instead of the 53 wells drilled on the field. The second step consists in estimate, by EDK, an average velocity field, from the interval velocity taken from the 53 wells. For the wells without sonic log it was considered only two points: one in the Eocene and other in the Reservoir bottom, both easily identified at density logs and wells tied to the seismic section. The interval velocity field first computed, after the conversion to the average velocity field, was used as an external drift. The robust drift model applied is accepted due to the good correlation between interval well velocity and the average velocity of the drift (Figure 3). In this estimative, now computed in a regular grid, the average velocity field, obtained from a stratigraphic grid acted as a guide in the interpolation well to well, making possible to estimate the field as if it was conformed with the structural of the area. The average velocity field obtained, Figure 4, was applied to the seismic data into a T-D conversion algorithm which results are very reasonable (Figure 5).

Conclusions

In face of the good results presented it is possible to say that to T-D conversion the ordinary kriging estimative of interval velocity field is better than the estimative of average velocity field of the normal incidence (V_{NI}), because it was computed along geological correlation lines generated by seismic section interpretation in time. In such a way the estimated field is able to reproduce the rapid variations in velocity generated by faults or pinch outs. A low density in wells with sonic logs harms its accuracy, however, even with a limited number of wells, the stratigraphic/structural character given by seismic interpretations will be preserved by the estimative process. Hence, the obtained field, after its conversion to average velocity, can be used as a drift in the kriging with external drift algorithm, to estimate a V_{NI} field with better results than those obtained with ordinary kriging. This methodology is very good to fields where the NMO velocities are not available or do not present good correlation with well velocities.

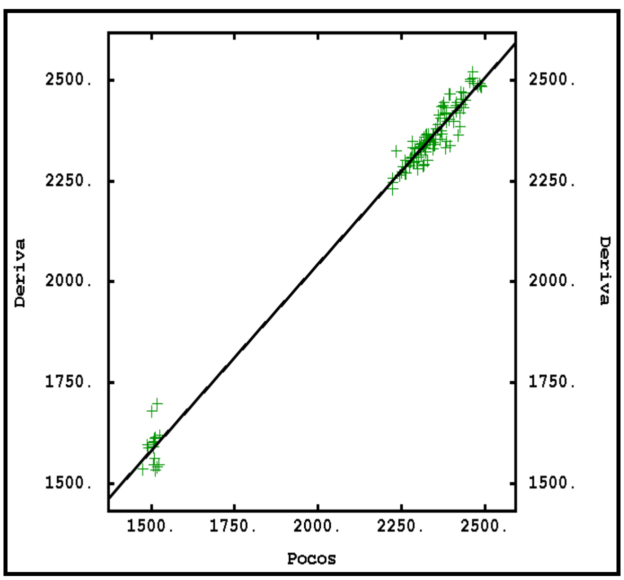

Figure 3 - Scatterplot of well interval velocity (50 wells) an average velocity.

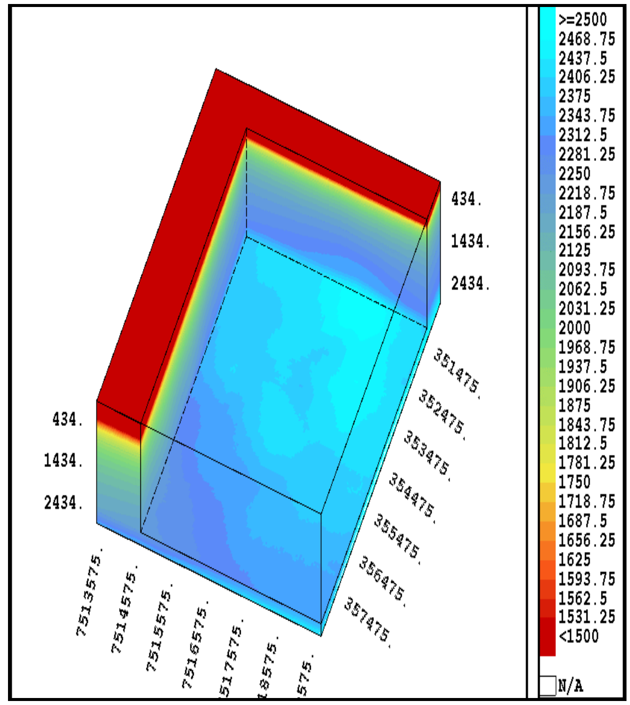

Figure 4: Average velocity field estimated by EDK.

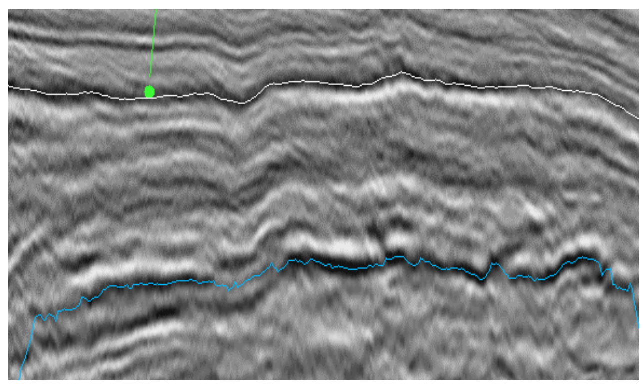

Figure 5 - Seismic section in depth obtained by applying the average velocity filed of Figure 4. The Eocene250 is mapped in white and the reservoir bottom in blue.

Acknowledgments

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