Seismic inversion for reservoir characterization Petroleum
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Abstract

Characterized a reservoir is predict its behavior to ensure that we will have an optimized production, and in the case of deviations, the plan development is adjusted by the updating of which is based on studies.

The aim of this study is to evaluate a model of petrophysical properties (porosity) characterized only by information from wells and compares it with a model characterized by wells and seismic data, a cube of acoustic impedances, based on geostatistical simulation methodologies and co-stochastic simulation.

Keywords

Petroleum Reservoir
Geostatistics
Acoustic Impedance
Porosity
Permeability
Uncertainty
Direct Sequential Simulation (DSS)

1.1. Introduction

Characterize a reservoir is predict its behavior to ensure that its behavior is consistent with expected, and in the case of deviations, the plan development is adjusted by the updating of which is based on studies.

For this it is essential to gather data that are acquired from different sources, methods and scales, such as laboratory data, wells, seismic data and production, and geological information, aiming to build a 3D model of porosity, permeability and saturation. This reservoir model is essential for the planning of the process of development of the field.

In many cases the only source of information available for the construction of reservoirs model is based solely on petrophysical readings, leading to unreliable models with uncertainty, high.

Thus, the modeling of petroleum reservoirs or systems aims at developing and
implementing mathematical and stochastic models for the characterization of petroleum reservoirs. It involves the construction of an oil of a reservoir for the purpose of improving the estimation of reserves decisions on the development of the field.

Of the wide variety of heterogeneous methods for characterizing the reservoir, the stochastic simulation algorithms, in general, are of great importance for the estimation procedures, since they allow to:

- Play more faithfully the basic statistics, histograms and the experimental variograms, and;
- Knowing the uncertainty of the variable associated with each location is sampled.

The reservoir and its characteristics

A reservoir is formed of one (or more) of subsurface formations containing fluids and/or gaseous hydrocarbons, of sedimentary origin (or not, in some exceptions). The reservoir rock is porous and permeable, and its structure is limited by the impermeable barriers that trap the hydrocarbons.

Figure 1.1 - Example of structural traps

A reservoir must have two fundamental properties of commercial interest to present:

- Porosity to contain fluids;
- Permeability to allow fluid flow through the reservoir to the producing wells.

Thus the porosity and the permeability is a key feature of a petroleum reservoir, for the production and accumulation of hydrocarbons.

1.1.2. Porosity

The porosity is the amount of voids or pores in the rock, which control the volume of fluid that may contain the rock. The amount of fluid existing in reservoir rock is a function of pore volume thereof.

Is defined mathematically as percentage porosity, as the relationship between pore volume (or air voids) and the total volume of rock.

\[
\phi(\%) = \frac{V_p}{V_t} \times 100 \quad [1]
\]

Where: - Porosity (%) - Volume of pores; - total volume of the rock

Note that the porosity does not contain information about the morphological parameters of the pores, such as surface area and/or the degree of connectivity. To describe the morphology of the pores, it is a function which takes the value 1 for the points \((x, y, z)\) located in the pores, or 0 to the point in the rock matrix. Using this function will be possible to represent the morphological characteristics of the porous medium. The porosity could be obtained from integral, represented by:

\[
\phi = \int_{V} \Omega(x, y, z) dV \quad [2]
\]

The porosity is distinguished in two forms, the effective and total. As regards the
disposal of the sediment can be classified as primary and secondary

1.1.3. Permeability

The permeability of the rock is defined as its conductivity to the fluid, i.e., the ability to allow fluid to pass through. Depends on the way the pores are interconnected, i.e., the effective porosity.

2.1. The geostatistic on the reservoir characterization

The geostatistic provides two different methods of calculation which usually boil down into two categories: i.e., estimation and simulation. Both techniques use the variogram and correlogram as measures of spatial continuity.

The common way of measuring the spatial representation is the variogram and correlogram.

The seismic inversion Geostatistics has been a technique commonly used to embed information in stochastic models of the Grid. Basically, the inversion methods geostatistics perform a sequential approximation in two steps: acoustic impedance values are simulated for each detail (a column of a grid and 3D) data based on the well and of spatial patterns as shown by the variogram; then in a second step, the impedance values are processed by a convolution with a known amplitude estimate for a given seismogram which can be compared with the real seismic.

2.1.1. Basic geostatsitics concepts

2.1.2. Exploratory data analysis

In exploratory data analysis, we characterize the statistical behaviour of the univariate and multivariate set of existing information. This step aims to extract all possible information about the data we have, so they are characterized and quantified the relationship between different types of data and information (from the seismic logs).

2.1.3. Univariate analysis of data

It is the analysis on a single variable, the main objective is to present the feature or the tendency of a data variable.

The arithmetic mean is a first example of one. It is usually represented by:

\[ m = \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \]  

[3]

The dispersion of the sample is usually calculated by the variance, which represents the mean of the squared differences between the observed values and the average of the variable. Is given by:

\[ S^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \]  

[4]

2.2. Bivariate analysis

It aims to study simultaneously two (or more) variables. Establish relationships between variables and determine whether the differences between the distributions of
these variables are statistically significant, with the purpose of searching for influences, causalities or coincidences.

2.2.1. Spatial continuity 
(variography)

The study of variography or spatial continuity aims at knowledge of the spatial dispersion of the experimental data and the degree of anisotropy between the variables in question.

The variogram is the instrument used for this purpose it is intended to represent quantitatively the variation of a regionalized phenomenon in space (Huijbregts, 1975).

2.2.3. Simulation and Direct Sequential Co-simulation (SSD-SSD and CO)

The direct sequential simulation (DSS) is a simulation method which uses the original variable does not require any processing, which is clearly an advantage over SSG SSI or will to co-simulation or simulation of continuous variables (Smith, 2006).

3.1. Case study and analysis of results

3.1.1. Variables in study

The initial information that serves as the subject of this paper consists of petrophysical data containing readings of values of acoustic impedance, porosity, permeability and acoustic impedance respective hub which will serve as secondary and supplementary information for the characterization and study of the wells.

The data, although synthetic, addressing a real case, proving to be sufficiently reliable to illustrate how to apply the methods to assess the impact geostatisticos qualitative and / or quantitative integration of seismic data in the construction of an oil reservoir petrophysical model.

These data are given in an oil field is containing 10 wells, whose dimension (in the directions X, Y, Z) is 50m 50m 61.

3.2. Univariate statistics 
(histograms)

3.2.1. Acoustic impedance

The acoustic impedance is defined as the product of the density ($\rho$) and the speed $v$ of the medium traversed by the seismic wave. The acoustic impedance can be clearly linked to many properties of the reservoir, such as the lithology and porosity constituents and some of the pores. 

$$I = \rho \times v$$
From the histogram we can get an idea of how the variable is distributed, we note that the average distribution of the sample is in the order of 7083.51, the variance can be considered high in the order of 2,460,129.06. You can also check that the probability distribution function which can be attributed seeing the histogram, it will be much like a normal distribution.

Can also be considered a nearly symmetrical histogram in which frequency is higher near the center, with a slight decrease markedly at the left and right of center. The mean and median can be considered similar and close to the center.

3.2.2. Porosity

The image shows the location of the wells, the wells have a low acoustic impedance, have very high values of porosity, this phenomenon can be explained because of the negative correlation between these two properties.

The histogram of this variable shows that the average porosity is 0.31 and the variance is 0.01. The distribution function which can be attributed to this normal histogram is asymmetric with extreme values, where the frequency is higher for high values of porosity.

3.2.3. Permeability
Figure 3.3 - Location and distribution of the permeability in the wells and the histogram data of permeability and its distribution function.

The image clearly shows that the wells show low values of permeability; this detail can indicate that the container has a good storing ability for hydrocarbons.

The histogram of this variable shows that this variable is the mean and variance 1086.96 is 97583.79. The median is practically equal to the average and are located in the center of the histogram, and the probability distribution function is similar to a normal distribution, be it a symmetrical histogram in which frequency is higher in the center or near this, and gradually decreases towards both sides symmetrically.

3.3. Spatial continuity (variography)

Experimental variograms were calculated for different directions, but I will mention only those of greatest interest, especially those representing the principal directions, because they give the idea of variable distribution without regard to a particular direction.

It is important to cite all the variograms were fitted using the exponential model is the one that best fits the variogram.

The direction is the main (90, 0), a minor (0, 0), minir 2 (0, 90) and the omni-directional (0, 0).

3.3.1. Acoustic impedance

3.3.2. Porosity
Initially it was made considering the SSD only information data from the wells and then co-SSD regarded as the cube of acoustic impedance as a secondary image. 30 simulations were performed for the impedance, porosity and permeability and calculated the mean and variance of each set of simulation to see how the data vary from simulation to simulation and to compare and quantify the uncertainty in each simulation method.

No need for a more detailed analysis of the behavior of each of the 30 simulated images, we performed the calculation of the variograms, histograms and basic statistics of the different representations and compared with the sample data from wells.

The following is a series of images corresponding to each set of simulations, as well as the mean and variance of each of the simulations 30 and their histograms. I have only one image for each simulation, since they have very similar visual aspects.

4.1. Acoustic Impedance

The DSS of this property of the reservoir (acoustic impedance) was based only on data from 10 wells, with the aim of improving the characterization of heterogeneity and incorporate the uncertainty in the estimate.

Marked by the low values of acoustic impedance, it can be seen (in the figure below) that this property distribution along the reservoir. At the top, continuous layers can be identified with low values of acoustic impedance, which may correspond to the main carrier range of hydrocarbons. The lower layers have continuities less pronounced, with average to high acoustic impedance.
Figure 4.1 - Picture of the 1st simulation of the acoustic impedance plane (x, y); perspective

As might be expected, the simultaneous analysis of these results to the images generated histograms, lets say that for the variable acoustic impedance, comparing the histograms of simulated values and the sampling of the wells, it appears in both the first class histograms values as a group most frequented, there is still an almost uniform distribution for the intermediate classes and a roughly similar mean and variance. However it is observed in both cases a weak values representative of the extreme right the average coefficient of variation and also low.

Figure 4.2 - Histogram of the simulation of acoustic impedance and histogram of the original data of acoustic impedance

Figure 4.3 - Variograms of the simulated acoustic impedance values from the DSS, and the theoretical model fitted to experimental variograms

Regarding the variogram with the main directions, the results are also extraordinary. The theoretical model of the actual values of the variogram fits well to the variogram of the simulated values.
### 4.1.2. Porosity

The histograms show that the variance is less than the simulation data for Pit although the average porosity in both cases are similar. However histograms have the same distribution of the samples, the distribution law which can be attributed to these histograms is asymmetric with normal extreme values, where the frequency is higher for high values of porosity. This similarity might suggest that this simulation is variable in accordance with the expected, ie, that the reflected simulation equiprobable set of images with a very close spatial variability of the sample data.

The variogram simulation analysis shows that the simulation of the variogram presents much resemblance to the original data, so that the exponential model was chosen to adjust the variogram, such as the sample data set of the porosity.
4.2. Direct Sequential Co-Simulation

On similarity of the DSS, there were 30 co-simulations (presented only in the first figure below) about 570 readings of porosity in 10 wells. The coefficient of correlation between porosity and Al is 0.84, which shows a strong interdependence between the spatial variables of interest, and validating the application of the methodology.

Figure 4.7 - Image of a co-simulation of the porosity in the plane (x, y); perspective

Figure 4.8 - Variograms of porosity values co-simulated from the DSS, and the theoretical model fitted to experimental variograms.

5. Conclusive Analysis

Having carried out 30 simulations for each of the variables and made the calculation of means and variances in each case, one can consider that the results were satisfactory. The simulations were conducted using the sequential simulation right in which I had in mind only the information of the wells.

The achievements obtained as a result of direct sequential simulation there were areas of high variability of the porosity and to a lesser extent to acoustic impedance. However, outputs that are obtained by direct co-simulation sequential co-located with local correlation, and for which used the image impedance of the hub as secondary information, and show less variability lowest uncertainty as to the previous method. Correlations and information from univariate and bivariate analysis were of great importance for the analysis and interpretation of images obtained after the simulations.

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