Comparison between recursive and sparse-spike inversion performed in a synthetic reference model

Sérgio Sacani Sancevero, UNICAMP, Rodrigo Portugal, UNICAMP, Armando Zaupa Remacre, UNICAMP

This paper was prepared for presentation at the 8th International Congress of The Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 14-18 September 2003.

Abstract

The use of three-dimensional (3D) seismic data has become a common way to identify the size and shape of sand bodies in hydrocarbon reservoir. However, in some cases the reservoirs are made up of a complex distribution of sand bodies and layers with subseismic resolution which directly affect the use of conventional seismic data in reservoir characterization processes. One way of increasing the reservoir characterization processes is of building a synthetic reference model where tools and algorithms used in the characterization of the oil field, such as seismic inversion and interpretation, can be tested and parameterized. In this work, we show the seismic inversion method applied to a model with realistic characteristics of turbidite reservoir with a complex distribution of sand bodies and subseismic layers. Synthetic model comparisons between two seismic inversion methods are performed and the advantages and disadvantages of these methods, in the processes of interpretation and individualization of target bodies, can be analyzed. Finally, we conclude that the parameterizations and conclusions about the synthetic model study can be transferred to real cases which have the same characteristics.

Introduction

Deep-water clastic reservoirs are important targets in worldwide petroleum exploration and production. These reservoirs are often characterized by a complex sand distribution which force the limits of conventional seismic data and geostatistical modeling and analysis tools (Caers, et. al, 2001). These complexities, often combined with high cost of deep-water development, require accurated reservoir characterization and recovery predictions. Hence, the heterogeneity of these kinds of reservoirs as well as the associated uncertainty in order to determine the involved risk of capital investment, must be accurately quantified. This quantification and analysis can be performed in the synthetic reference model with the advantage that the conclusions and interpretations can be done more easily because the various phenomena that affect the results can be isolated and separately analyzed. Another advantage in the use of synthetic reference model is the generation of a reference dataset for the validation of results.

The generation and study of a synthetic reference model for the testing and parameterization of algorithms used in the quantitative description of reservoirs, is a task that becomes more and more common in reservoir characterization processes. For this purpose, the object-based simulation can generate models that displays the crisp geometric shape of the desired reservoir bodies, which are consistent with the prior geological and morphological interpretations. Mao et al. (1999) create a reference dataset with the purpose of testing any algorithm for reservoir characterization. The reference dataset is created by object-based simulation and is a representative of a fluvial reservoir of North Sea. In this reference model, the authors make an exhaustive study about geological, petrophysical and geophysical modeling. According to Strebelle et al. (2002), the object-based simulation is used to create reservoir architecture that works as a training image for others modeling techniques and for testing methods used in reservoir characterization processes as well.

Jointly with the geological interpretations and modeling, the seismic data analysis provides complementary sources of information to model sand bodies in the reservoirs architetures. The seismic data provide a valuable information about the areal distribution of these target bodies. However, seismic data are available only in a coarse vertical resolution, more closely representing interval average rock properties, whereas well log facies data more closely represent point rock property (Yao, 2000).

When avaible, in general, 3-D seismic amplitude data can be used as an indicator of impedance change due to a change in rock facies. However, deep-water turbidite reservoirs are sometimes characterized by sandstones with thickness usually below the seimic resolution. Under these conditions, the analysis of seismic amplitude data provides great uncertainty in the prediction of these kinds of reservoirs. In these cases, the analysis of seismic amplitude data alone does not provide sufficient understanding of the complex layout of the reservoir sandstone. One solution to this problem is to perform a seismic inversion from amplitude to acoustic impedance.

The advantages of seismic inversion are that while seismic reflection data represent an interface property where reflection events are due to relative changes in acoustic impedance of adjacent rock layers, the acoustic impedance is a physical rock property, given as the product of density and velocity measured by well data. Thus for any quantitative interpretation of seismic data in the characterization of thin layers that constitutes these kinds of reservoirs, seismic inversion is a possible solution, i.e., transform the post stack seismic reflectivity traces into acoustic impedance data, providing the opportunity to individualize the reservoir bodies (Chopra, 2001).

There are several different techniques or methodologies that are commonly used to perform acoustic impedance inversion. In this work, we show the application of two of them. The first one is the recursive inversion, that is the most basic type of inversion and also the earliest developed methodology to recover the acoustic impedance from seismic data. This method essentially assumes that the seismic amplitudes are proportional to reflection coefficient and then transforms the input seismic trace to acoustic impedance data. The second method is the sparse-spike inversion. This method gives an estimate of the reflectivity series that would approximate the seismic data with a minimum number (sparse) of spikes. Non uniqueness is taken care of by applying the sparse reflectivity criterion (Chopra 2001).

The objective of this work is to show and compare the results obtained by both methods of seismic inversion performed on the synthetic reference model with some characteristics of deep water turbidite reservoirs.

Methodology

The synthetic reference model that we used in this work was made by Boolean simulation. This technique inserts predefined geometrical forms in the determined grid, aiming to reproduce the desired characteristics. The synthetic reference model is formed by small bodies, which are representative of sandstone lithology inserted in a shale background. The relative size of modeled bodies and the shapes were obtained in the previous works available in literature (see e.g. Bruhn, 1998). The sand bodies generated by Boolean simulation have some characteristics of turbidite reservoir and are specifically created to simulate thin layers, in order to study the behavior of seismic data in the limit conditions of seismic resolution.

After the geometric modeling, several petrophysical attributes, such as compressional velocities and densities were generated by stochastic simulation. These attributes were used in correspondence to each body or background, according to the kind of rock requested.

This final model was used as an input for the seismic modeling, using the convolutional model given by equation (1), which basically consists of the convolution of a wavelet with the acoustic vertical reflectivity, obtained from the reference model.:

$$s(t) = w(t) \otimes r(t) + n(t). \qquad (1)$$

After seismic modeling, the seismic cube was used as input for the processes of seismic interpretation and inversion, which are composed mainly of four steps:

- The construction of subsurface model which represents the low-frequency component of seismic data;
- The wavelet extraction from seismic data;
- The actual inversion routine;
- The merging of the inverted seismic traces with the low-frequency component.

The reconstruction of the subsurface model is carried out by the interpretation of main horizons, which are identified in the seismic data. These horizons form a solid volume of representative geology of the area. The earth model is used in forward modeling by populating the 3D volume with wireline logs at every location of the seismic trace.

The wavelet extraction is performed through the tying of seismic data and the well profiles. It also is essentially made by deriving a wavelet, which minimizes the misfit between synthetic and seismic data. The extraction of wavelet from the seismic data can be done by taking a number of seismic traces around the well location (Salleh, et al. 1999).

The recursive trace inversion used in this work is based on the following recursive algorithm:

$$Z_i = Z_0 \prod \frac{1+r_i}{1-r_i} \ . \qquad (2)$$

The algorithm, in order to produce meaningful results, requires that the input seismic trace must correspond to the bandlimited earth reflectivity function and be a zero phase with positive seismic trace amplitude corresponding to a positive reflection coefficient.

The constrained sparse-spike inversion (CSSI) creates an acoustic impedance model from seismic reflection data. At each trace position, the seismic data is modeled as the convolution of a set of reflection coefficients with a wavelet. The reflection coefficients define the impedance. The processes are controlled by a set of constraints based on a priori information from some known geology or from well logs. These constraints effectively limit the range of potential solutions to those that have geophysical and geology significance.

The final step in the generation of acoustic impedance model is trace merging, because after the creation of acoustic impedance volumes, three frequency ranges are often well recognized:

- The low frequency band, the range of which is on the lowest seismic frequency;
- The seismic band, ranging from the lowest seismic frequency to the highest seismic frequency;
- The high frequency band, ranging from the highest seismic frequency to the highest well logs frequency.

The purpose of trace merging module is to merge the dataset, providing low frequency band information for the dataset, which already has the seismic bandwidth information and, therefore, creates a bandpass filter in any model file.

Results and analysis

The reference model used in this work is composed of four horizontal layers, with lateral dimensions of 10 km and total depth of 0.3 km. All the layers have constant velocity and density, except for the third layer. This third layer is a reservoir section that was generated by Boolean simulation and has some realistic characteristics of turbidite reservoirs, such as subseismic sand bodies with complex distribution. A perspective view of this third layer that represents the synthetic reservoir is shown in Figure 1.

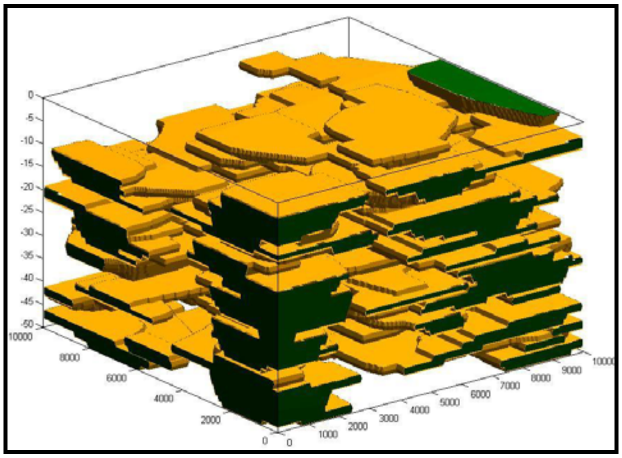

Figure 1: Third layer that represents the reservoir in synthetic reference model.

After the geometrical modeling, the reference model was filled in with two petrophysics properties: compressional velocity and density. From these two properties, it is possible to extract other important ones for the reservoir, such as porosity, permeability and acoustic impedance, used in seismic modeling. A section across the center of the model showing a impedance property is presented in Figure 2. This section is used in all comparisons in this work.

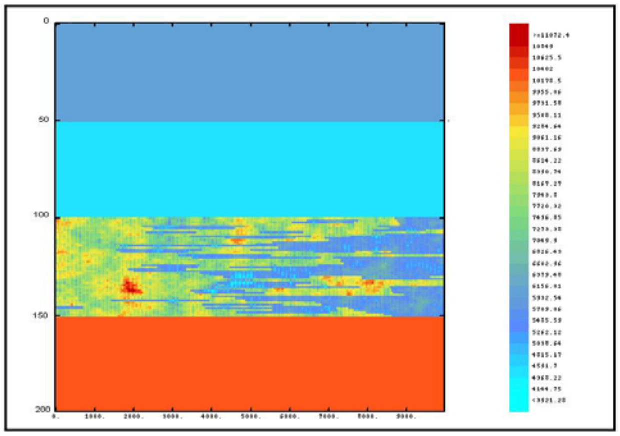

Figure 2: Impedance section.

In the sequence, seismic modeling was carried out using the convolutional model according to equation (1). This seismic data will be used in the sequence of the work where are the seismic inversions are performed. a 3D view of seismic data with the wells used in this work is presented in Figure 3.

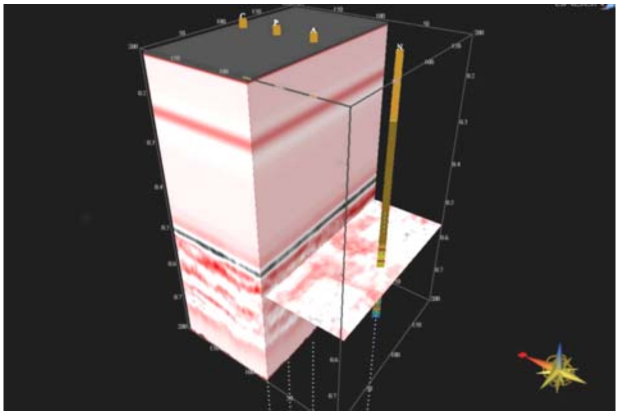

Figure 3: Perspective view of synthetic seismic data set, also showing the wells used in this work.

The wavelet extraction in our process was not necessary because a wavelet acquired in real seismic acquisition performed on a region geologically equivalent to our reference model was used.

This wavelet was used for both seismic modeling and inversion. Therefore we assumed that this wavelet already fitted this seismic data, implying that it was not necessary to extract a new wavelet. This wavelet is shown in Figure 4.

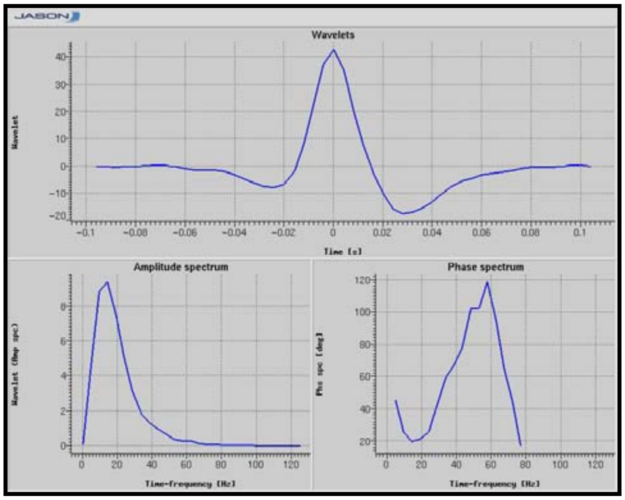

Figure 4: Wavelet used for generation of seismic data and realization of seismic inversion.

The results of both methods of seismic inversion in synthetic reference model lead to a number of significant interpretations. Firstly, for comparison, Figure 5 shows the seismic data and original impedance both restricted to the reservoir portion. Also, in this figure, we can observe problems early mentioned about seismic resolution concerning the reproduction of thin layers. Some complexities present in the original geological model could not be identified given seismic conventional of amplitude.

In this way, in an attempt to solve this resolution problem a seismic inversion using two methods with the objective of comparing the results obtained for impedance data was performed.

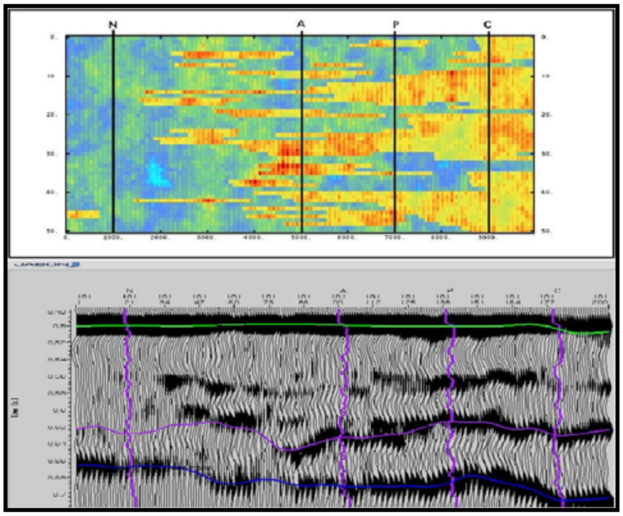

Figure 5: Comparison between original impedance data with seismic data.

First we performed a recursive inversion to obtain properties of each whole layer instead of obtaining properties given by the seismic amplitude, which is given along the layers interfaces. The part I of Figure 6 shows a section of the result of recursive seismic inversion jointly with the seismic data and the part II of Figure 6 shows a section of the original impedance data.

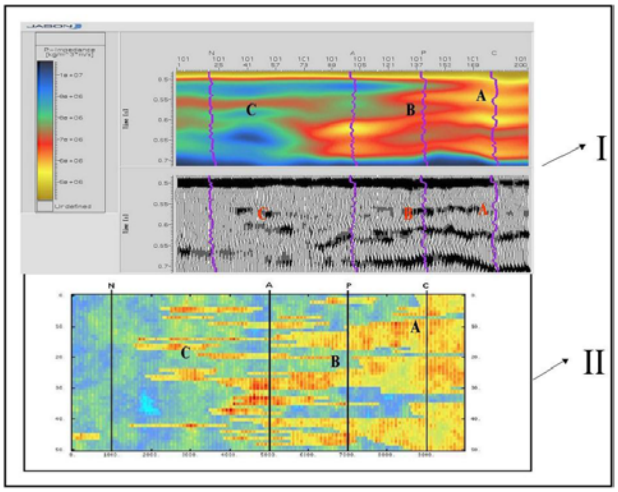

Figure 6: Comparison between inverted data by recursive method, seismic data and original impedance data.

When we compare the result of recursive inversion with seismic data, the benefits carried out by seismic inversion for acoustic impedance can be observed. They are clearly observed in portions A and B, where in the inverted data the layers that are part of the original impedance data can be observed, while in the seismic data these layers are not individualized. In portion C of Figure 6, we can observe, in the acoustic impedance data, the extrapolation of some features observed both in original impedance data and seismic data. The recursive inversion showed good results for individualization of some layers and carried out benefits for the interpretation. Another observed advantage in the use of recursive inversion is the short CPU time.

After recursive seismic inversion we performed a sparse-spike inversion. Figure 7 presents a similar visualization of Figure 6, where the inverted data by sparse-spike inversion, the seismic data and the original impedance data are shown.

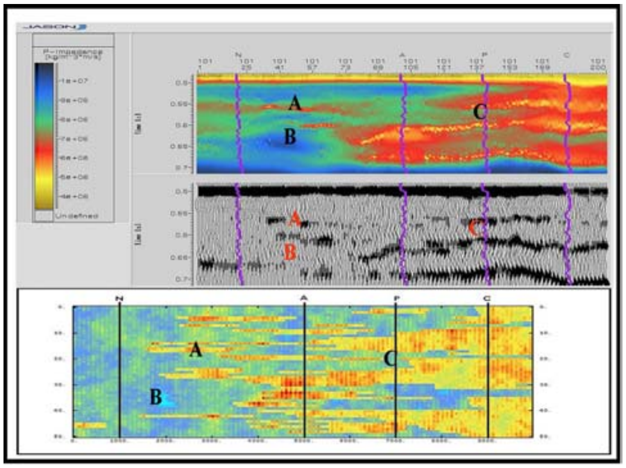

Figure 7: Comparison between inverted data by sparse-spike method, seismic data and original impedance data.

In region A we observe that there are two bright spots in the seismic data that correspond to two thin layers in the original impedance data, these layers are resolved by sparse-spike inversion. In region B an anomaly of high impedance that was reproduced successfully by the seismic inversion is observed. In region C, we can observe that the inverted data shows the layers that exist in original impedance data and these layers are satisfactory resolved by impedance data.

Comparisons between two inverted data are shown In Figure 8.

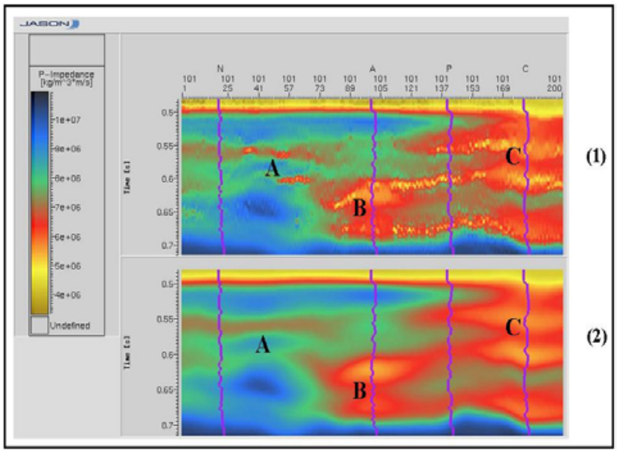

Figure 8: Comparison between inverted data by sparse-spike (1) and recursive (2) algorithms.

Analyzing Figure 8, we can observe that in region A the layers are better individualized in sparse-spike inversion, and as was observed early, it is according to original impedance data. In the region B both sparse-spike and recursive algorithm produced the same results, because this region is formed by a great number of thin layers that is impossible to be resolved in the seismic data and in the inverted data. Finally in region C, the layers are better individualized by sparse-spike inversion, where the three more thick layers with better resolution than recursive inversion are revealed.

Conclusions

We conclude that it is possible to use the Boolean simulation to create a realistic synthetic reference reservoir, which possess specific characteristics such as thin layers.

Beyond that, we showed that this reference model could be used to show the advantages of using seismic inversion, mainly concerning the individualization of structures present in situations under the seismic resolution.

When sparse-spike and recursive algorithms are compared, we can observe sparse-spike inversion individualized thin layers, therefore resulting in an improved resolution. On the other hand, with the help of recursive inversion we can observe the benefits in seismic interpretation. Although the recursive algorithm cannot resolve some thin layers, due to its short CPU time, it can be used to improve the interpretation of horizons that could not be observed in seismic data.

Finally, due to the difficulty of defining the parameters used in seismic inversion for real data, mainly in sparse-spike method, the parameters defined for this reference model can be reused in the processing of real data that comes from regions with the same characteristics presents in the discussed reference model.

References

Bruhn, C., 1998, Petroleum Geology of Rift and Passive margin Turbidite systems: Brazilian and Worldwide Examples, AAPG International Conference.

Caers, J.; Avseth, P., 2001, Mukerji, T. Geostatistical Integration of Rock Physics, Seismic Amplitudes and Geological Model in North-Sea Turbidite Systems, SPE 71321.

Chopra, S., 2001, Integrating Coherence Cube Imaging and Seismic Inversion, CSEG Recorder.

Mao, S. , 1999, Journel, A., G. Generation of a reference petrophysical/seismic data set: the Stanford IV reservoir, SCRF Report.

Salleh, M., Ronghe, S., 1999, Reservoir Characterization on Thin Sands in South West Ampa 21 Area (BLK11) Using Seismic Inversion, SEG Expanded Abstracts.

Strebelle, S.; Payrazyan, K.; Caers, J. , 2002, Modeling of Dee-Water Turbidite Reservoir Conditional to Seismic Data Using Multiple-Point Geostatistics, SPE 77425.

Yao, T.; Chopra, 2000, A. Integration of Seismic Attribute Map into 3D Facies Modeling, Journal of Petroleum Science and Engineering.

Acknowledgements

The authors gratefully acknowledge Jason Geosystems for using the Jason Geoscience Workbench and the National Agency of Petroleum (ANP) from financial support.