Statistical Seismic Facies Estimation from Pseudo Impedance Data

Carlos A. da Cunha Filho, Mauren P. Ruthner, Rogério C. Gontijo and Sávio H. M. de Almeida, Petrobras

Abstract

Usual methods for facies classification are based on characteristics associated with variations in the shape and amplitude of the seismic pulse for the top or base of the seismic interval of interest. There are three drawbacks to this procedure: effects of overlapping adjacent pulses can interfere in the process, the estimation of the facies is linked to a geological discontinuity (interface) and not to the geological property (layer), and finally there is no explicit connection between the geological property and its seismic expression. The proposed method is based on identification of facies from seismic properties directly associated with the physical aspects of the rocks without interference from seismic pulse and can thus be consistent with the geological characteristics of different facies types.

Introduction

The relationship between some significant geological characteristics of a depositional system and the contrasts in their mechanical properties visible by seismic data has been investigated over the years (Vail et al. 1977; Tipper, 1993; Hardage e Remington, 1999). Cronostratigraphic events such as discontinuities, litostratigraphic variations or changes in facies may configure different patterns of seismic reflexions. The way these patterns are registered and subsequently processed to form a coherent seismic image is conditioned to the limited spectral bandwidth of the seismic signal. Abrupt, gradational or cyclic variations will generate different patterns of seismic images that can lead to false interpretation of its geological significance. Zeng et al. (1998) show that genetically distinct depositional sequences may appear as an unique seismic event due to the limited resolution of the data. Moreover images of the amplitude of seismic reflexions are not always the most appropriate way to construct the underlying geological model since these amplitudes are related to the rock contrasts and not to the rocks themselves. Gradation of facies, for instance, cannot be interpreted on an amplitude section. Impedance (or Pseudo Impedance) allow a more reliable interpretation of the geological framework, since they represent rock properties and not interfaces between distinct rock layers.

Theory

Several methods for differentiation and classification of facies based on different kinds of data and attributes can be found in the literature. Most of them use amplitudes from conventional processing data or attributes related to the shape of the seismic pulse, to characterize the seismic facies. Saggaf et al. (2003) uses an algorithm based on neural networks to identify and then group traces from short time windows around an event of interest into distinct classes. Matos et al. (2007) adopt a similar strategy, but based on use of Kohoen maps and wavelet transform to identify singularities into the interval of interest. Both methods are restricted to a horizon of interest and the final product is a seismic facies map. Mukerji et al. (2001) uses directly impedance volumes (acoustic and elastic) obtained from an inversion of near and far offsets to generate a seismic facies volume through geo statistical techniques.

The input data for the present technology is a volume of pseudo impedance which is obtained by removing the residual seismic pulse with a workflow that includes iterative deconvolution and spectral colouring. More details of the generation of the pseudo impedance volume can be found in Rosa (2010). After that the volume is integrated and filtered to eliminate low frequency noise that is enhanced during the process. Than an interval of interest is taken from the pseudo impedance volume parallel to a horizon of the top or of the base of the reservoir or both simultaneously as a reference and this interval is flattened. The present methodology of classification makes simultaneous use of two attributes of the flattened interval of the pseudo impedance volume:

- Mean Volume (M) – obtained from the vertical moving average of the Pseudo Impedance Volume (P). The computation of this volume depends on parameter Nv – number of samples for computation of the vertical mean,

  $$M(i,j,k) = \frac{1}{N_v} \sum_{l=i-N_v/2}^{i+N_v/2} P(l,j,k),$$

  where i and l are vertical indices (time or depth) and j and k are spatial indices (x and y). Nv is odd, so Nv / 2 actually represents (Nv – 1) / 2.

- Deviation Volume (D) – obtained from horizontal moving average of the square of the difference between the value of the sample from the pseudo Impedance Volume and the Mean Volume. The computation of this volume depends on parameter Nh – number of samples for computation of the horizontal average,

  $$D(i,j,k) = \sqrt{\frac{1}{N_h} \sum_{l=j-N_h/2}^{j+N_h/2} \frac{\left[P(i,l,k) - M(i,l,k)\right]^2}{\left[M(i,l,k)^2 + \varepsilon\right]^{\alpha}}},$$

where ε is a stabilization factor (ε << || M ||) e α is a normalization factor that can assume values between 0 and 1. When α assume the value of 0 the deviation is not normalized and when α assume the value of 1 the deviation is normalized. Intermediate values can be used.

Then the distribution curves of the values associated to each one of these volumes are computed as seen in the histograms in figure 1(a,b). The little triangles indicate boundary values (that can be adjusted by the user) which delimitate three distinct regions of low, medium and high values. The criterion of classification of a given sample is based on its position relatively to the boundary values of the two histograms. According to this, nine distinct classes are defined (1c). These classes can be configured by adjusting the four boundary values and the normalization factor taking in account well logs and geological background. An example of the seismic facies distribution according to this criterion is shown in figure 1d.

Examples

The classification was applied to two different data from offshore Brazil in time domain, one from pre salt carbonates and other from Maastrichian sandstones deposit along paleo channels. In the pre salt carbonates the reference horizon was the base of the salt. The chosen interval comprised 8ms above the salt base and 500ms below it. Than this sub volume was flattened and the volumes of Mean and Deviation were calculated, with a half window of 3 samples in both directions (time and space). For this data the most appropriate Mean Volume cut-offs were 0-31.6% for the low values, 31.6-73.0% for the medium values and 73.0-100% for the high values. For the Deviation Volume the cut-offs were 0-45%, 45-79.99% and 79.9-100% for the low, medium and high values respectively. Figure 2 shows the comparison of the pseudo impedance data (a) with the seismic facies obtained with the method (b). For this case the most interesting facies is the one painted with light blue and yellow colours in figure 2. Also in figure 2 the two yellow vertical lines correspond to planned well locations whose primary objective is the first light blue plus yellow level. And the region surrounded by the red ellipse shows some side lobes related to deposition that were emphasized with the facies classification method. Figure 3 shows a zoom of the region surrounded by the red elipse in figure 2b.

In the Maastrichian sandstones the reference horizon is midway between top and bottom of the reservoir. The selected interval comprises 60ms above the horizon and 40ms below it. The objective here was to determine if the reservoir of a possible well location would be connected with the reservoir of a drilled well, where oil was found. For this data the Mean Volume cut-offs were 0-8.0% for the low values, 8.0-33.0% for the medium values and 33.0-100% for the high values. For the Deviation Volume the cut-offs were 0-94.0%, 94.0-95.0% and 95.0-100% for the low, medium and high values respectively. Half spatial and temporal windows were 3 samples. Figure 4 shows in (a) the pseudo impedance, in (b) the facies classification and in (c) a geobody extracted from a seed inserted in the centre of the region surrounded by the red ellipse in the facies classification. This region corresponds to the reservoir where oil was found (POC_1). The extension of the geobody of figure 4c confirmed the connection between the two well locations as expected by the interpreter of the area. Future drilling confirmed the prediction.

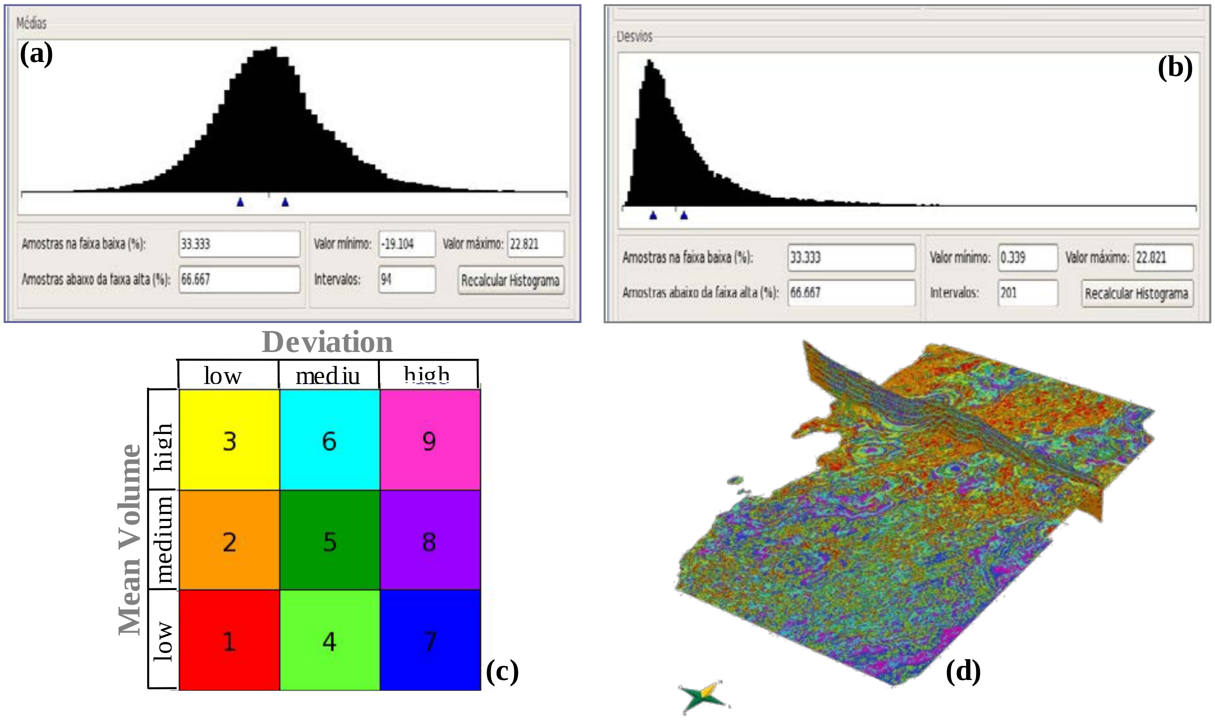

Figure 1: (a) Histogram of the Mean Volume. (b) Histogram of the Deviation Volume (c) Diagram with an example of the facies classification criterion. (d) A time-slice and a inline section of pre salt data from Brazil showing the seismic facies obtained with the method described.

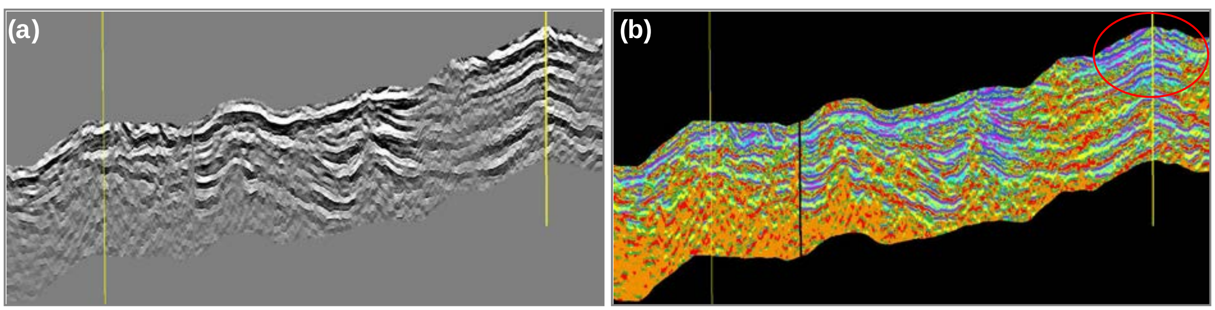

Figure 2: Comparision of Pseudo impedance data (a) and seismic facies obtained with the method (b). The region surrounded by the red elipse (b) shows some lobes related to deposition that were emphasized with the facies classification.

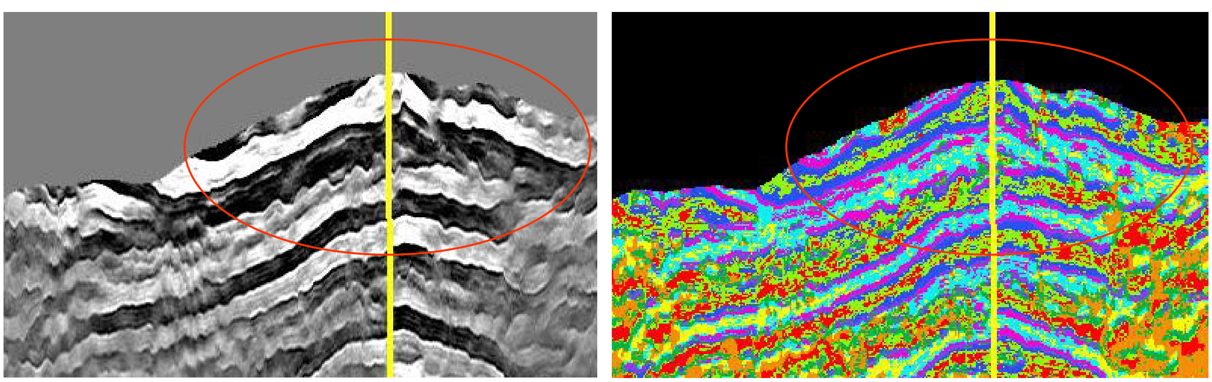

Figure 3: Zoom of the region surrounded by the red elipse in figure 2b showing some side lobes related to deposition that were emphasized with the facies classification.method.

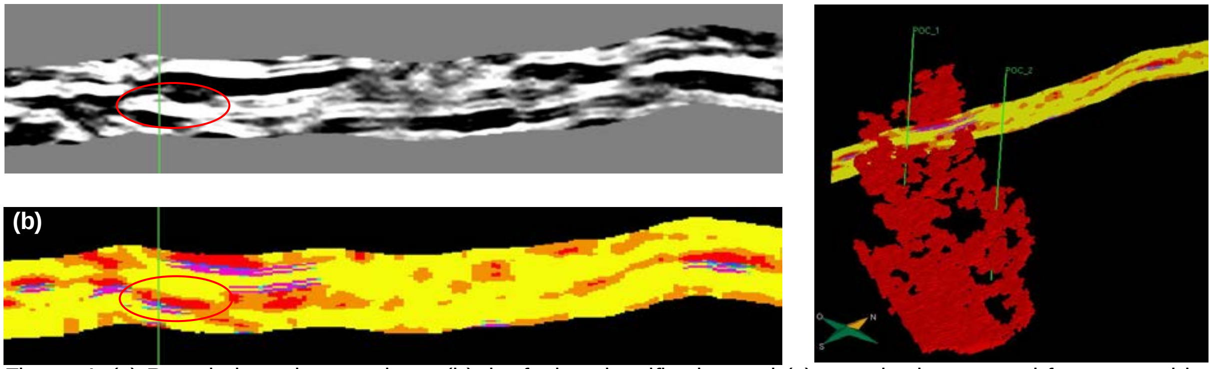

Figure 4: (a) Pseudo impedance volume,(b) the facies classification and (c) a geobody extracted from a seed inserted in the centre of the region surrounded by the red ellipse.

Conclusions

One of the advantages of the method presented here is that it is based on pseudo impedance which is much closer to geology than conventional amplitude because it deals with layers instead of interfaces. In comparison to pseudo impedance itself it brings additional geological information as shown in the example of figure 3. Other important advantage is the interactivity that allows the interpreter to adjust the obtained results to the geological model he has in mind. Besides that, it is possible to extract geobodies from the classification, have a 3D view of the body of interest and even have an estimate of the volume.

Acknowledgments

We thank Petrobras for the authorization to present this work.

References

Hardage, B.A., and Remington, R.L. [1999] 3-D seismic stratal-surface concepts applied to the interpretation of a fluvial channel system deposited in a high-accomodation environment. *Geophysics,* **64**, 609-620.

Matos, M.C., Osório, P.L.M., and Johann, P.R.S. [2007] Unsupervised seismic facies analysis using wavelet transform and self-organizing maps. *Geophysics*, **72**, 9-21.

Mukerji, T., Jorstad, A., Avseth, P., Mavko, G., and Granli, J.R. [2001] Mapping lithofacies and pore-fluid probabilities in a North Sea reservoir: Seismic inversions and statistical rock physics. *Geophysics*, **66**, 988-1001.

Rosa, A. L. R. [2010] *Análise do Sinal Sísmico*. Sociedade Brasileira de Geofísica, Rio de Janeiro.

Saagaf, M.M., Toksoz, M.N., and Marhoon, M.I. [2003] Seismic facies classification and identification by competitive neural networks. *Geophysics*, **68**, 1984-1999.

Tipper, J. C. [1993] Do seismic reflections necessarily have chronostratigraphic significance? *Geology*, **130**, 47-55.

Vail, P. R., and Mitchum, R. M. Jr. [1977] Seismic stratigraphy and global changes of sea level, part 1, overview in Payton, C. E. ed., Seismic stratigraphy – Applications to hydrocarbon exploration. *Am. Assn. Petr. Geol. Memoir,* **26**, 51-52

Zeng, H., Backus, M.M., Barrow, K.T., and Tyler, N. [1998] Stratal slicing, Part I: Realistic 3D seismic model. *Geophysics*, **63**, 502-513.

Zeng, H., Henry, S.C. and Riola, J.P. [1998] Stratal slicing, Part II: Real 3D seismic data. *Geophysics*, **63**, 514-522.