Preconditioning of Brazilian land seismic data for AVO analysis

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Abstract

Brazilian northeastern land seismic data is known to produce poor quality images due to a complex geology in the near surface and irregular topography. Most of the time the use of processing steps that degenerates the relative amplitude of seismic data is mandatory to enhance the structural features present in the data. For this reason, there are a lot of discussions about the use AVO (Amplitude versus Offset) analysis on this kind of data. In this study we demonstrate that with a careful preconditioning using inverse-Q and multispectral filtering based on curvelet transform can elevate the changes of successful AVO attribute study on this region of Brazil.

Introduction

Clues to the litology and fluid content of an exploration target may be revealed by analyzing variation of seismic reflectivity with source-receiver offset (Resnick J.R., 1993). A variety of factor influence the field recorded seismic data (coupling of source and receiver, transmission losses, ground roll, geometric spreading and noise), all of this effects should be treated correctly by the processing flow in other to eliminate undesired components (different types of noise) and compensate natural losses of energy due to intrinsic subsurface properties (dispersion and absorption).
When the seismic data is processed with true amplitude in mind, one can use this information to extract multiple attributes that are direct hydrocarbon indicators (DHIs) and use this information to minimize the explorations risk.

The goal of AVO analysis is to extract rock parameters by analyzing seismic amplitude as a function of offset, more correctly as a function of angle. The Zoeppritz equations gives the exact plane wave amplitudes of a reflected P-wave as a function of angle, but does not give us an intuitive understanding of how these amplitudes relate to the various physical rock parameters. Over the last three decades many authors presented approximation to this equation. Assuming a small variation in the layer properties and angle of incidence, Aki and Richards proposed a three term expression as a function of angular reflections coefficients A, B, and C:

$$R(\phi) \approx A + B\sin^2(\phi) + C\sin^2(\phi)\tan^2(\phi) \qquad (1)$$

Where R is the reflection coefficient as a function of the incident angle and:

$$A = \frac{1}{2}\left(\frac{\Delta Vp}{\langle Vp\rangle} + \frac{\Delta\rho}{\langle\rho\rangle}\right); \qquad (2)$$

$$B = \frac{1}{2}\frac{\Delta Vp}{\langle Vp\rangle} - 2\left(\frac{Vs}{\langle Vp\rangle}\right)^2\left(2\frac{\Delta Vs}{\langle Vs\rangle} + \frac{\Delta\rho}{\langle\rho\rangle}\right); \qquad (3)$$

$$C = \frac{1}{2}\left(\frac{\Delta Vp}{\langle Vp\rangle}\right), \qquad (4)$$

Where $\Delta Vp = (Vp_2 - Vp_1), \Delta Vs = (Vs_2 - Vs_1), \Delta\rho = (\rho_2 - \rho_1)$, are the change in compressional velocity, shear velocity and density across the interface and $\langle Vp\rangle = (\frac{Vp_2 + Vp_1}{2}), \langle Vs\rangle = (\frac{Vs_2 + Vs_1}{2})$, $\langle\rho\rangle = (\frac{\rho_2 + \rho_1}{2})$ is the average change of compressional velocity, shear velocity and density across the interface. The subscripts correspond to one (overlying) and two (underlying) media.

Other approximations based on Aki and Richards work simplified equation (1), and at the same time related the reflectivity as a function of angle, to other meaningful rock attribute changes (eg., Wiggins, 1983 assumed a constant Vp/Vs ratio and rearranged (1) as a function of Rp and Rs zero-offset reflectivity), (Shuey, 1985; Verm and Hilterman, 1995 assumed a constant density and a linear relationship between Vp and Vs and derived a well known approximation as a function of the change in Poisson ration between interfaces.

A useful way to express these approximations in the simple form of:

$$R(\phi) \approx Rp + B\sin^2(\phi) \qquad (5)$$

This equation is linear if we plot R as a function of $\sin^2(\phi)$. Performing a linear regression analysis on the seismic amplitudes, we can estimates of both intercept Rp, and gradient B. At this point, it is intuitively that we have to give the correct treatment to relative amplitude and noise of the seismic data to have and appropriate estimate of these parameters. Attributes derived from Rp and B can highlight interesting properties of the subsurface like change in fluid or change in lithology, and used to aid explorationist in the process of decision making about prospective areas on a field.

In this work we focus the discussion on the conditioning of the seismic data for AVO analysis. Since this is and extensively area of study, we concentrated on two basic effects that should be treated when processing data for AVO attribute derivation (Earth absorption and randon noise).

Method

The data used in this study consists of a 3D land survey in the Northestern part of Brazil. The field is a gas production field and was discovered in the mid's 70. In this test, we elaborated two basic processing flow, one with no preconditioning and the other we added Q-compensation and curvelet filtering. Bellow is the processing flow:

i) Trace edition
ii) Static correction
iii) Basic denoising
iv) Spherical Divergence correction
v) Surface consistent deconvolution
vi) Velocity analysis
vii) NMO correction
viii) Residual static correction;

Time migrations is currently being applied in the reprocessing of this data, and CRP's wore not available at the time of this test, so for this reason we worked and compared the results with the CMP gather and not the CRP gather .

Using the nearest well available we modeled and extracted AVO attributes that enhanced the target area. This result was used as basis for comparing the preconditioning test of the data.

Compensating Earth´s intrinsic attenuation with inverse-Q filtering

Intrinsic attenuation is caused by the fact that even homogeneous sedimentary rocks are not perfectly elastic. Seismic Inverse Q filtering is the process that employs a wave propagation reversal procedure that compensates energy absorption and correct wavelet distortion caused by velocity dispersion. The phenomenon can be expressed as a transfer function $G(\omega,t)$, a plane wave of angular frequency ω and propagation time t (Luh, 1993):

$$G(\omega,t) = \exp(\omega t/2Q + i(\omega t/\pi Q)\ln\omega/\omega_0) \qquad (6)$$

Where Q is the quality factor and ω_0 is the reference wavelet frequency. The process used to compensate the absorption effect can be done by simulating the Q effect on a model and them deriving an inverse Q operator. Applying this operator to the data will compensate distortions of amplitude and phase. To model the Q effect an estimated Q profile must be inputted together with the a velocity field. A constant Q profile of 150 was used in this study.

Random noise attenuation in the curvelet domain

Random noise in general will contaminate the relative amplitude of the seismic signal by adding unwanted energy. Typical bandpass filter will not preserve data outside its designed window and can eliminate important information present in the higher frequency content of the seismic data like reflection of thin layers. A common technique used to attenuate noise and first arrivals is the frequency-wavenumber (FK) filtering, in this domain there is a great danger of attenuating reflected energy at mid and far offsets, distorting the true AVO response. The treatment of noise should be done in a more selective manner; in this case we used a signal decomposition based on curvelet transform. By using this technique, the data can be decomposed in a way that we can control frequency, space and angle content of the signal and have a greater chance of removing only the noise content of the data. The curvelet transform can be though as a sequence of parabolic dilations, rotations, and translations to a specifically shaped function ψ (Candes,2003) this shape functions are controlled by three main parameter the scale a, the location b and the orientation θ .

$$\psi_{a,b,\phi}(x) = a^{-\frac{3}{4}}\psi(D_a R_\phi(x-b)), \qquad (7)$$
$$D_a = \begin{pmatrix} 1/a & 0 \\ 0 & 1/\sqrt{a} \end{pmatrix}$$

The transform can be expressed as:

$$f(a,b,\phi) = \sum \left\langle f(x), \psi_{a,b,\phi} \right\rangle \psi_{a,b,\phi} \qquad (8)$$

Here D_a is a parabolic scaling matrix, R_ϕ is a rotation by θ radians, and for $(x1,x2) \in R^2$ $\psi(x1,x2)$ is our seismic data, $f(a,b,\phi)$ are the curvelets coefficients. The strategy chosen for random noise filtering was to order the data in common offset gathers and threshold the smaller scales in all angle directions.

Examples

Figure (1) shows the synthetic seismogram generated using the control well. The reservoir sands, in this case, presented a large decay in the Poisson ratio and a much higher impedance than the overlying shale, this produced a AVO class 1 anomaly illustrated in Figure (2) . We should expect that any other region with the same behavior can indicate other potential reservoirs.

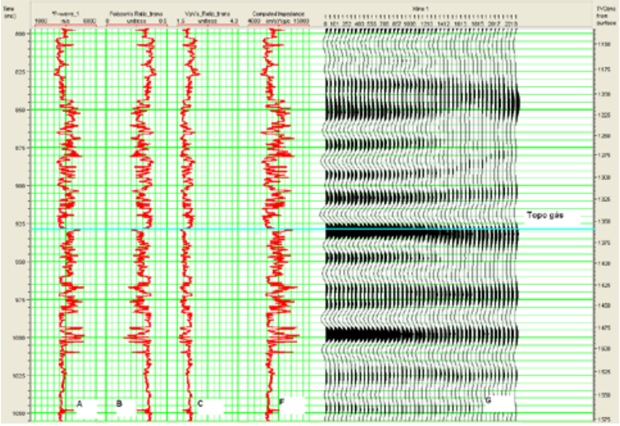

Figure 1 – A) P-wave curve B) Calculated Poisson ratio curve C) Vp/Vs ratio curve and the synthetic seismogram.

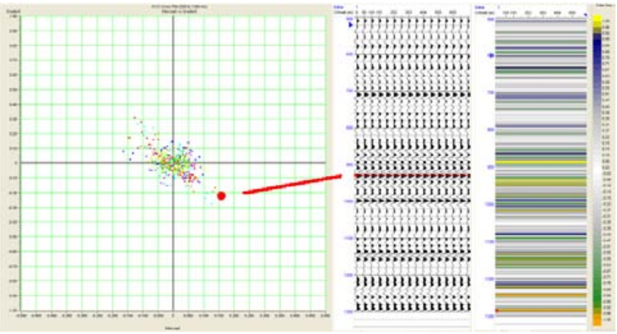

Figure 2 - i) Intercept X Gradient plot of the synthetic. The red point is the calculated value from the least square fiting of the reflection to a three term Aki and Richard approximation from the top of the gas reservoir. ii) Synthetic seismogram showing the top of gas reflection. iii) Calculated scaled Poisson ratio AVO attribute showing a high contrast from the overlying and underlyng formations.

We can notice how the data point that corresponds to the top of gas reservoir deviates from the background as expected. In the next step, we will compare the Intercept X Gradient, response and the scaled Poisson ratio attribute from the data before and after preconditioning.

Results

After the curvelet filtering and Q-compensation we can notice a much cleaner CDP gather, highlighting events that wore contaminated with noise. Also the phase adjustment from the Q-filtering seems to align better the reflections. Figure (3) shows one CMP before and after data preconditioning.

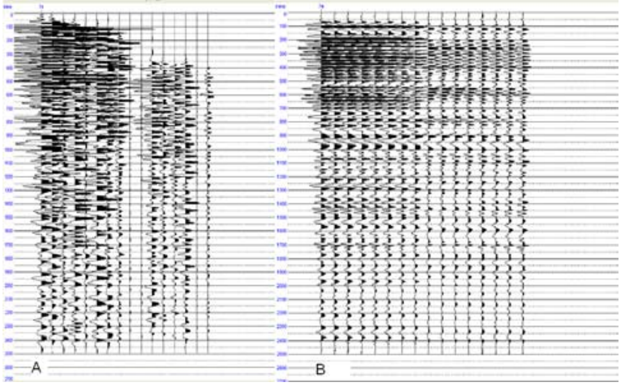

Figure 3 – A) CMP gather before precondition. B) CMP gather after precondition.

Figure (4) compares the Intercept X Gradient plot of the data before and after the preconditioning. We can observe that the background scatters in the case where no treatment to the data is done, in the opposite, when the preconditioning was applied the back ground trend has the same behavior then the modeled data. After Intercept X Gradient analysis, the scaled Poisson ratio was extracted, and analyzed. Figure (5) shows the result. It is clear that the data with preconditioning has o closer match to the expected response.

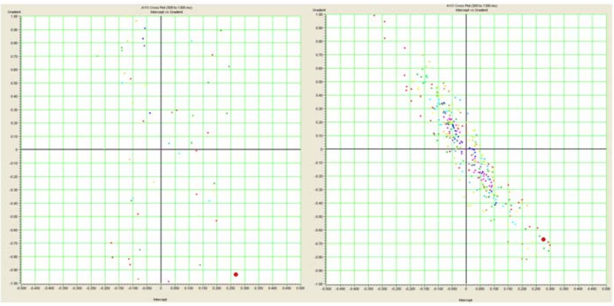

Figure 4 – Intercep X Gradient analysis of the CMP gather. First the data with no preconditioning, second the data precontioning. The big red point corresponds to the time event of 870 ms, which from the interpretation correspons with the same formation of the gas reservoir in the control well.

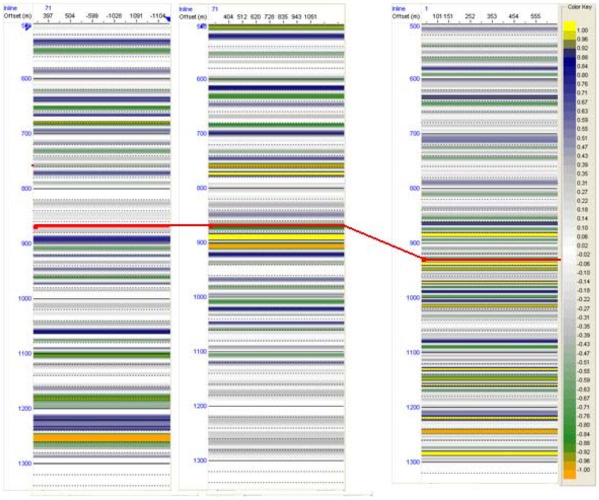

Figure 5 – Scaled Poisson ratio AVO attribute extracted from the data; from left to right i) First panel the data has no preconditioning: ii) Second panel, data with preconditioning, iii) Third panel attribute extracted from the synthetic data.

The last step was to derive the scaled Poisson ratio for the entire volume. Figure (6) shows the results. We can see that the data with no preconditioning has absence of any anomaly, In the case where the data was treated we can observe the presence of negative Poisson ratio anomalies that suggest the presence of hydrocarbons. Since the data was not yet migrated, can be the causing of the appearance of other (maybe fake) anomalies at earlier events.

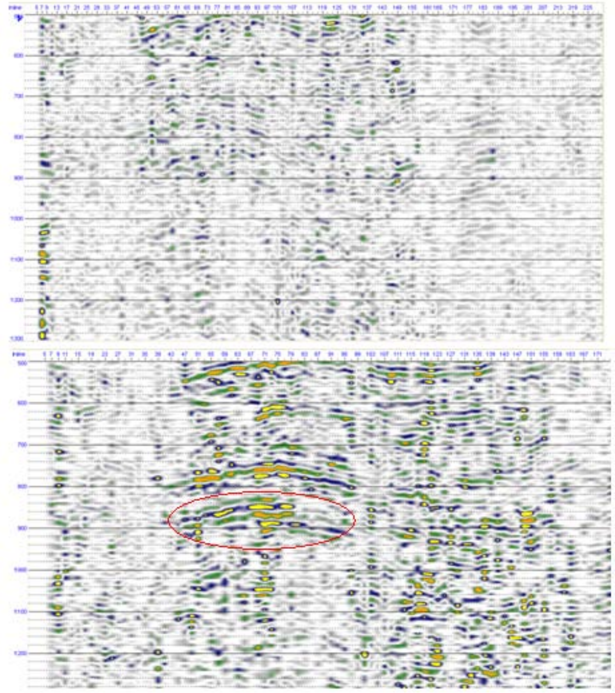

Figure 6 – Results of a section of scaled Poisson ratio attribute; i) Top figure, data with no preconditioning; ii) Bottom figure data after preconditioning. The red circle matches the interpretation of a potential reservoir.

Conclusions

We demonstrated that with a careful seismic preconditioning we are able to develop AVO studies in areas of complex geology and poor seismic data quality as in the Northestern region of Brazil. In this case the most impacting part of the processing flow was the Q-compensation and the random noise elimination. After correcting this effects, the AVO response on the data was enhanced. Other effects may influence the AVO response and should also be part of any processing flow for AVO studies (Residual move out, trim static, etc).

Unfortuly the seismic data that overlaps the exact area of the control well has a really low s/n ratio due to the presence of conglomerates that unable any imaging or any other type of analysis to validate the study.

Acknowledgments

We would like to thanks COWAN for the permission to publish the data in this work. We would also like to thanks the Invision AVO team and the Stratageo processing team for valid discussions and data QC.

References

Aki, K., Richards, P.G., 1980. Quantitative Seismology, Freeman and Co., New York.

Candès, E.J., 2003, What is a Curvelet ?, Notice of the AMS, Volume 50 Number 11.

Castagna, J. P., Batzle, M. L., and Eastwood, R. L. 1985, Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks: Geophysics, Vol. 50, p.571-581.

Castagna, J. P. and Smith S. W., 1994, Comparison of AVO indicators: a modeling study: Geophysics, Vol.59, No.12, p.1849-1855.

Fatti, J. L., Smith G. C., Vail, P. J., Strauss P. J., and Levitt, P.R. 1994, Detection of gas in sandstone reservoirs using AVO analysis: a 3-D seismic case history using the Geostack technique: Geophysics, Vol.59, No.9, p.1362-1376.

Luh, P., 1993, Wavelet attenuation and AVO. In OOffset-Dependent Reflectivity: Theory and practice of AVO analisys (ed. Castagna, J. and Backus, M) Tulsa: Soc. Expl. Geophys., 317-332

Gray, D., Goodway, B., Chen, T. 1999, Bridging the gap – using AVO to detect fundamental elastic constants: EAGE 61st Conference – Helsink, Finland.

Resnik, J. R., 1993, Seismic data processing for AVO analisys

Smith, G. C. and Gidlow, P. M. 1987, Weighted stacking for rock property estimation and detection of gas: Geophysical Prospecting, 35, p.993-1014.

Smith, G. C. and Sutherland, R. A. 1996, The fluid factor as an AVO indicator: Geophysics, Vol.61, No.5, p.1425-1428.

Ursenbach, C.P. and Stewart, R. R. 2001, Extending AVO inversion techniques: CREWES report.

Smith, T. M., Sondergeld, C. H., and Rai, C. S.2003, Gassmann fluid substitution: A tutorial: Geophysics, V.68,No.2,p.430-440.

Shuey, R.T. 1985, A simplification of the Zoeppritz equations: Geophysics, V.50, p.609-614.

Wiggins, R., Kenny, G. S., and McClure, C. D., 1985, Common-depth-point method for determining and displaying the shear-velocity reflectivities of a geologicformation: Patent US4534019.