



Integrated Seismic Inversion and Quantification of Reservoir Properties in GOM Onshore and Offshore Basins

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Western Geco

Summary

The goal of seismic inversion is to invert for subsurface elastic properties so reservoir quality rocks may be identified and petrophysical properties quantified. Integrated prestack seismic inversion is a newly developed prestack inversion technique for inverting seismic data into elastic impedance and density. The method described in Poggiagliolmi et al. (Poggiagliolmi et al., 1994) and Roberts, et al. (Roberts, et al., 2005) integrates several major technologies, including AVO processing and analysis, well-log editing and calibration, Prestack Waveform Inversion (PSWI, Mallick, et al., 2000), wavelet processing, and post-stack inversion. The outputs of this inversion are high-resolution absolute acoustic and shear impedance and density volumes consistent with the seismic data and the well-log data. The inverted elastic parameter volumes are useful for detailed interpretation of lithofacies and pore-fluid contents in the subsurface. Combined with rock physics modeling and rock property mapping through Lithofacies (Bachrach, et al., 2004) and the joint porosity-saturation inversion, the method provides a powerful tool for quantitative reservoir description and characterization. The final results are the most-probable litho-class, porosity, and saturation with uncertainties of prediction at every sample point in the 3-D volume. We have been applying this method in identifying and characterizing reservoirs in the Gulf of Mexico onshore and offshore basins and in other basins. In this paper we discuss in details the application of the method for Woodbine reservoirs in East Texas. We also provide examples of work done in offshore Gulf of Mexico (GOM) basins.

Introduction

Woodbine sandstone reservoirs of East Texas are known for prolific stratigraphic oil and gas production. Although first discovered in the 1930s, many new fields continue to be discovered throughout the trend. The Woodbine sands were deposited during the upper Cretaceous by a prograding deltaic system that extended out into shelf and slope environments. The reservoirs in the study area are stratigraphically bounded by the Buda Limestone formation below, and the Austin Chalk formation above, both producing very continuous, distinct horizons. The Woodbine sand shingles (Figure 1) truncate at a major unconformity just below the overlying Austin Chalk. These Woodbine sandstones tend to have very low porosity, but can range from 2 to 24%. The porosity estimation of these Woodbine reservoirs from the 3-D data is very critical in reducing the drilling risk in this trend. Because the Woodbine sandstones tend to be thin and sparsely inter-bedded with shale, the high reflectivity at the Austin Chalk interface has a dimming effect on the reflection images of sand-shale boundaries in the Woodbine zone immediately below. This was an important challenge in the inversion process. The initial study was to test the feasibility of the method over 25 sq miles. The success in this phase led to an extension of the study area to about 100 sq. miles.

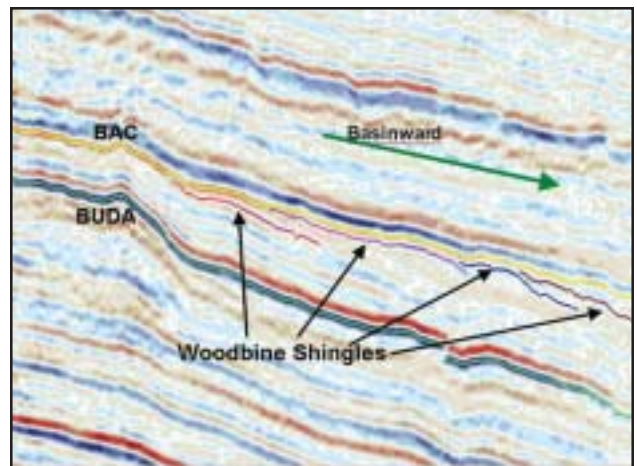


Fig.1 : Woodbine sand shingles bounded by the Base Austin Chalk (BAC) and the Top Buda horizons.

Inversion process

Multiattribute seismic inversion (MASI) integrates borehole and surface seismic data. After editing and processing borehole data and preconditioning prestack seismic data, the process of inversion followed the workflow as shown in Figure 2. A three-term AVO analysis method provided acoustic Impedance (I_p), shear impedance (I_s), and density reflectivity volumes. Each of these volumes was then

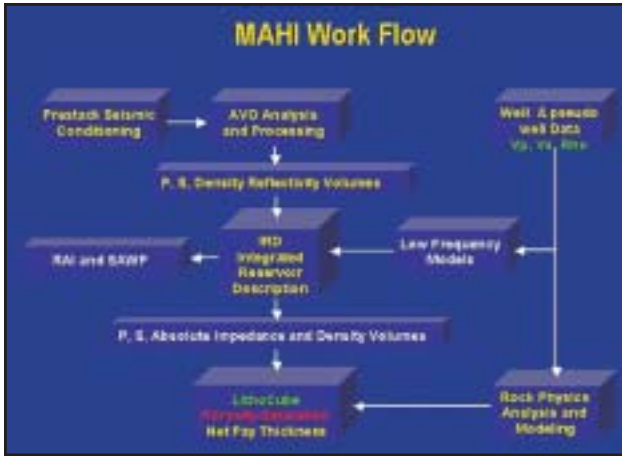


Fig. 2 : Multiattribute seismic inversion work flow.

independently wavelet-processed and inverted for changes in the elastic parameters at each sample point in a fixed time window. The wavelet extraction and inversion followed the methods of integrated reservoir description (IRD), (Poggiagliolmi and Allred, 1994). PSWI (Mallick, et al., 2000) pseudo-log curves generated from prestack gathers at multiple locations were added to the well log curves to build the low-frequency background models for the impedance and density volumes, which were then used for calibrating the elastic parameters to the absolute values. The rock physics analysis and modeling, together with the petrophysical data from the wells, provided the basis for lithofacies classes, the derivation of the probability density functions, and the transformation of the absolute elastic parameters to the lithoclass maximum a-posteriori (MAP) values, and finally to the porosity and the saturation properties through the joint porosity-saturation inversion (Bachrach and Dutta, 2004).

Rock physics analysis

A detailed rock physics analysis of edited log data was carried out for the elastic properties of rocks in the Woodbine zone. The scatter plots of bulk and shear moduli and density (\bar{n}), and various combinations thereof, versus the petrophysical properties—volume of clay (V_c), porosity ($\bar{\phi}$), and saturation (S_w), provided a quantitative measure of their spatial variation (Figure 3). This analysis also identified four litho-classes within the Woodbine zone: Shale, brine sand, poor-quality pay sand, and high-quality pay sand. The probability density functions for each of the classes were also computed from the rock physics analysis. Figure 4 shows the log-based probability density functions for I_p , I_s , and \bar{n} for each class. Rock physics analysis and modeling showed the relationship between S_w , V_c , and $\bar{\phi}$ on I_p , I_s , and density. These were used in qualitative interpretation and then for quantitative estimates through LithoCube and porosity-saturation inversion.

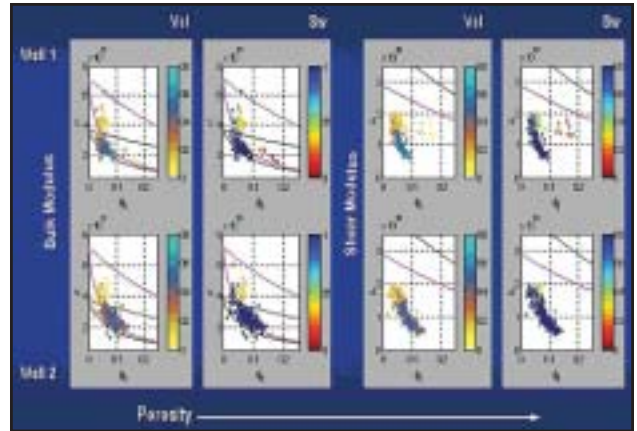


Fig.3: Bulk and shear moduli as a function of porosity with volume % of shale in color for two wells.

Seismic data conditioning

The proper conditioning of prestack data is important for meaningful inversion. The data were previously processed through an amplitude-preserving prestack time migration (PSTM) processing sequence. For the inversion study, we took the PSTM gathers and carried out additional refinement of gathers through application of a mild F-K filter, an aggressive parabolic Radon transform based demultiple process and a trimmed mean filter.

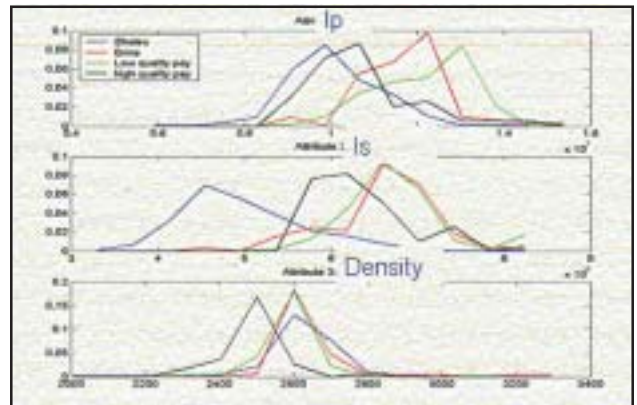


Fig.4: Frequency distributions of lithofacies classes from log data.

The parameters for these processes were optimized using a flow that outputs AVO attributes, the signal-to-noise ratio of the attributes, and the character of wavelets from the attributes along specific well-tie lines. The flow is shown schematically in Figure 5.

Wavelet processing and inversion

Accurately estimating the wavelet and affecting its shape are of paramount importance in optimal resolution



enhancement. The spatially adaptive wavelet processing (SAWP) method of Poggiagliolmi and Allred (1994), which uses a least squares deconvolution of the seismic traces by the well reflectivity series, was applied independently to each of the three AVO reflectivity volumes— I_p , I_s , and \bar{n} . The wavelets for the different attributes varied considerably, but for each attribute type, the spatial variation was reasonable. The goodness of fit for well ties was also very high for each attribute. The SAWP results on the PSTM stack along a 3-D inline are compared in Figures 6. The final wavelet was a zero-phase wavelet with little energy in the side lobes. The inversion results for contrasts in I_p , I_s , and density and the resulting well-ties are shown in figures 7-9. The absolute impedance and density volumes were computed after low-frequency compensation.

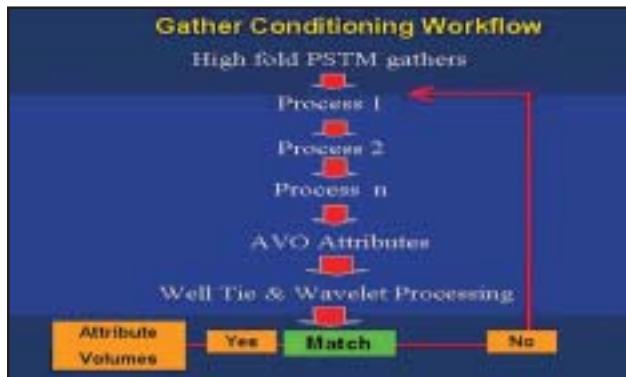


Fig. 5: Workflow for optimizing gather conditioning process parameters.

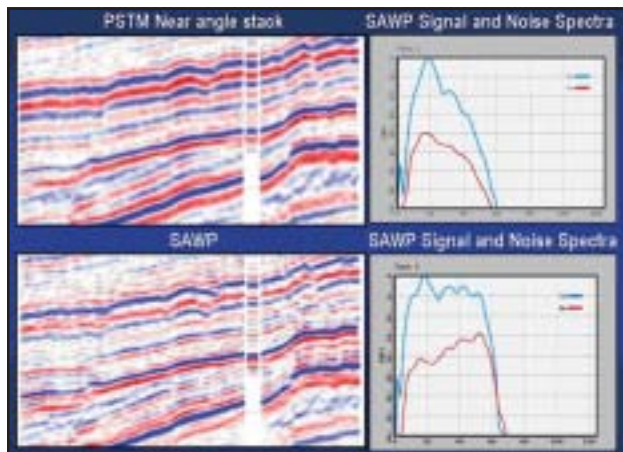


Fig. 6 : PSTM near-angle stack and the corresponding SAWP along a line through a well.. The signal and noise spectra are shown on the right.

Porosity and saturation

The absolute impedances and density, along with the rock physics analysis results, were input to lithofacies analysis (Bachrach et al., 2004) and then to the joint-porosity-

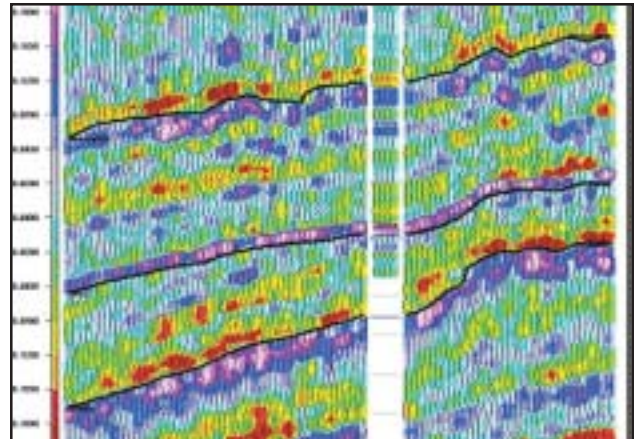


Fig. 7: I_p contrasts along an inline with well-tie.

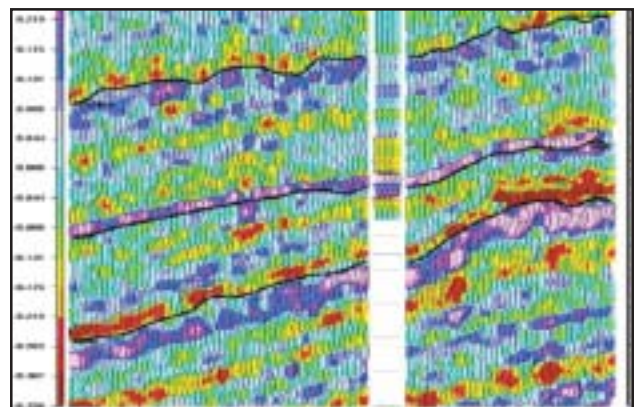


Fig.8 : I_s contrasts for the same inline.

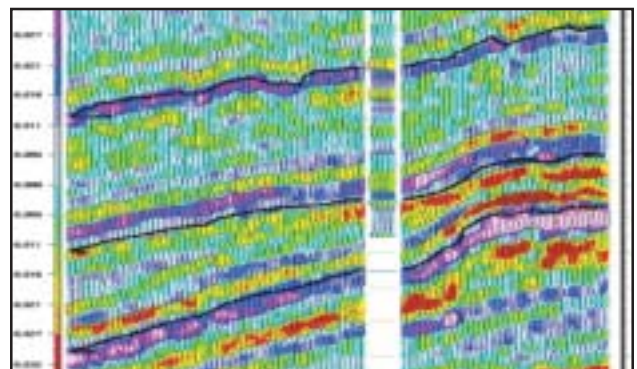


Fig.9 : Density contrasts for the same inline.

saturation estimation (Bachrach and Dutta, 2004). This was done with a simulation-inversion process, which used a Markov Chain, Monte Carlo (MCMC) simulation and the *maximum a-posteriori* rule. An error analysis in the impedance and density estimation was carried out and the results were included in the lithofacies analysis and the porosity-saturation inversion. The most probable porosity estimates for each sample were then summed over a time window and a statistical mean value was computed. These

mean porosity results for a 40ms window below the BAC are displayed in Figures 10 and 11 with analysis using I_p and I_s only and I_p , I_s , and density, respectively. The inclusion of density provided a more conservative prediction than without it. The feasibility study area was later extended to a larger area. The probability maps for the four Litho-classes—shale, brine sand, low-quality hydrocarbon, and high-quality hydrocarbon sand at the Austin Chalk boundary are shown in figure 12.

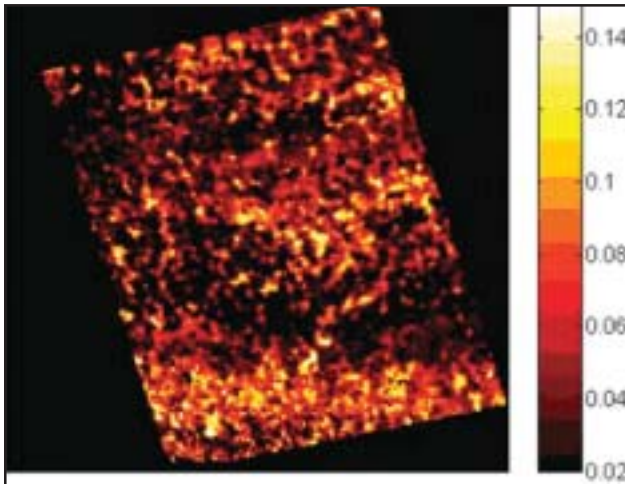


Fig.10 : Mean porosity map using I_p and I_s only

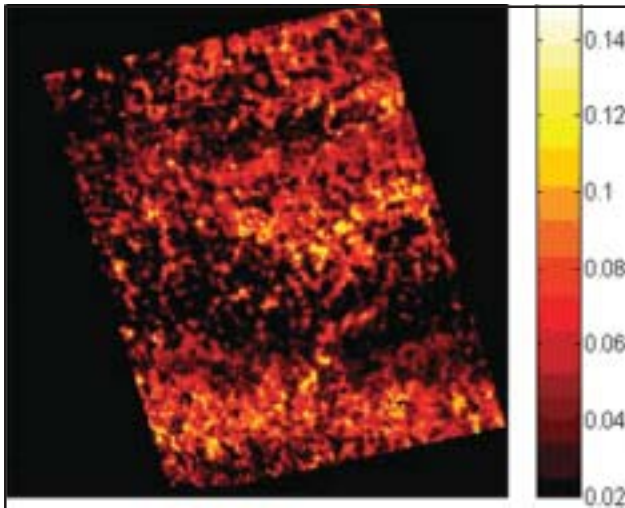


Fig.11: Mean porosity map using I_p , I_s , and density

Offshore GOM example

The method is equally applicable in other basins. The deep water Gulf of Mexico is a very active area for reservoir characterization. In the study that we just completed, one main objective was to improve the spatial resolution of turbidite sand reservoirs so the appraisal wells

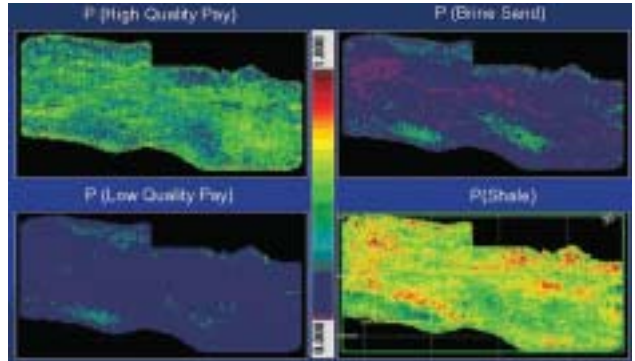


Fig.12: Litho probability maps for the Base Austin Chalk horizon. Four litho-classes high quality pay, low quality pay, brine sand, and shale are shown.

could be drilled with reduced risk and the reservoir heterogeneity could be understood. The work provided high-quality reservoir delineation, predicting hydrocarbon sand lithology volume, porosity, and saturation over a large area. Figure 13 shows an example of the hydrocarbon probability map at a deep, substantially dipping horizon.

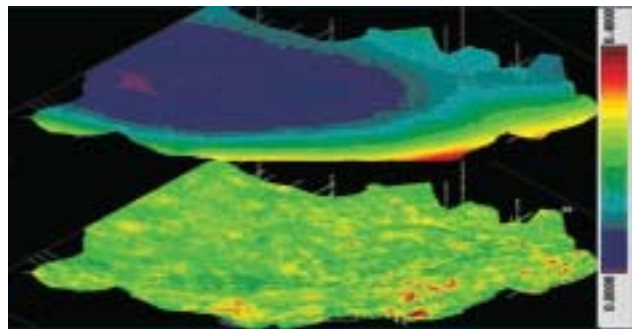


Fig.13 : The hydrocarbon sand probability map at a reservoir in offshore GOM. The water depth in this area is over 3000 ft.

Conclusions

We have applied multiattribute seismic inversion for integrated reservoir characterization of Woodbine sandstones. Using the lithofacies analysis and porosity-saturation inversion schemes, we then mapped absolute impedances and density to porosity and saturation. The final results are most probable estimates of porosity and saturation with uncertainty, for each sample point of the study volume. The quantitative results are being utilized to reduce the drilling risks in the Woodbine trend and in other basins of the Gulf of Mexico.

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