Impedance inversion in a structurally complex carbonate environment, Abu Dhabi, UAE case study

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Summary

Post-stack seismic inversion to acoustic impedance (Pendrel and Van Riel, 1997) was successfully performed on a 3D seismic volume over a large carbonate (ramp-type environment) field using an integrated iterative inversion workflow. The inversion results helped generate a structural model that more closely represents true subsurface geology and predicted reservoir porosity. The inversion minimized tuning effects and extended the useable bandwidth of the seismic information by removing the wavelet and its side lobe interference effects (Buxton Latimer et al., 2000). The acoustic impedance results from the inversion showed improved amplitudes and were used to predict a porosity model for the reservoir layers. The well data showed a good porosity-impedance relationship that was applied to convert inverted acoustic impedance into a porosity model for the field.

Introduction

It is often assumed that carbonate reservoirs are uniform with good lateral continuity and have minimal internal barriers to flow or changes in lithology. Although these carbonate reservoirs consist of a relatively uniform homogeneous southern portion, a series of complex prograding clinoforms exists in the north, which contain both dense and porous layers (Fitchen, 1997). The structural complexities of the reservoir in the north, along with the associated thin bed issues, created many challenges in the inversion project. These challenges were successfully overcome by using the Integrated Iterative Inversion (Triple-I) workflow shown in Table 1.

1. Qualitative seismic-to-well ties
2. Initial horizon interpretation based on seismic
3. Quantitative seismic-to-well ties with wavelet estimation
4. First pass seismic inversion for relative acoustic impedance (AI) result
5. Horizon adjustment using relative AI results
6. Seismic-to-well tie validation using AI results
7. Horizon validation, with well, geologic and sequence stratigraphy information
8. Final seismic inversion with appropriate constraints
9. Low frequency AI model built from well data
10. Merging of relative with low frequency AI for total AI result
11. Total AI validation, with well, geologic and sequence stratigraphy information
12. Porosity prediction from total AI
13. Validation of all results

Table 1: Triple-I workflow. An integrated iterative inversion work flow for getting the maximum value out of all available data.

The results show that reservoir porosity in the field was more truthfully predicted using the aforementioned Triple-I workflow. The simulated porosity honored all available data. This included the inverted impedance (and hence porosity prediction) which was optimally bounded (temporally and laterally) via a complex clinoform dependent structural framework and impedance earth model. The earth model, was ultimately merged with the AI results for a more constrained unique inversion solution.

Method

Well log-to-seismic calibration is a critical first-step not only when interpreting the seismic, but vital prior to impedance modeling and inversion (Table-1). Figure 1 shows a representative, quantitative seismic-to-well tie. The seismic image in the left panel shows good agreement with the synthetic (center panel) generated from the log impedance data and the estimated wavelet. The right panel shows the difference (seismic minus synthetic) and represents the unexplained seismic energy. Differences between the seismic and synthetic appear to correlate with coherent noise in the seismic data. The strong seismic event at 1420 ms, for example appears within the Nahr Umr shale, which should have only weak events based on available well log impedance information.

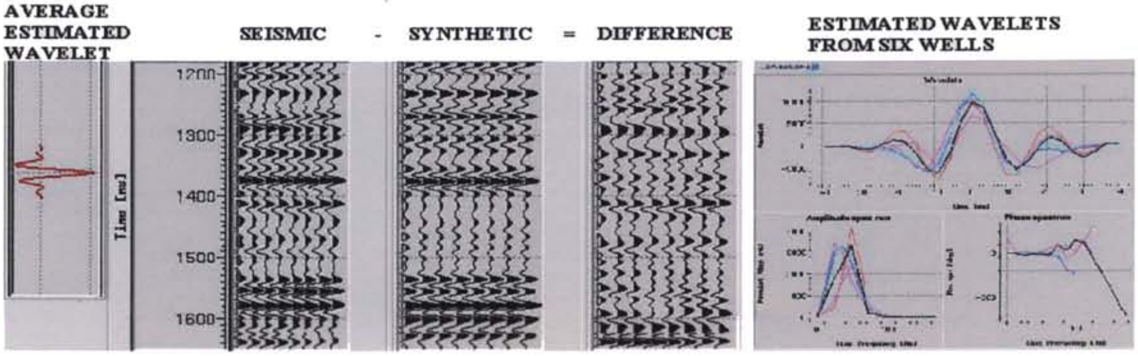

Figure 1. Representative seismic-to-well tie and estimated wavelets for six independent wells. Good well ties and a stable wavelet was obtained.

Wavelets estimated from six independent wells are shown on the right side of Figure 1. The estimated wavelets are in good agreement with a stable phase spectrum out to about 65-hertz. Differences in the amplitude spectrum are related to variations in the time windows used for the wavelet estimation. Discrepancies in the side lobes are most likely related to the coherent seismic noise and high random noise content above 65 hertz.

Horizons were mapped between wells in a more consistent manner using the inversion results. This was especially true when mapping relatively thinner, dipping clinoform structures (Figure 3) in North areas of the reservoirs. Figure 2 shows how an original key horizon mapped on the seismic image changes when the inversion results are used. Wavelet interference effects and tuning in the seismic image make it more difficult to properly follow an interface, as opposed to the inversion where these effects are minimized. Mapping thin layer effects at or below seismic resolution were resolved using an integrated approach with seismic, wells, inversion results, geologic information and other data as necessary. Moreover, complex clinoform horizons fit all available data, including the inversion results, within the current resolution limits.

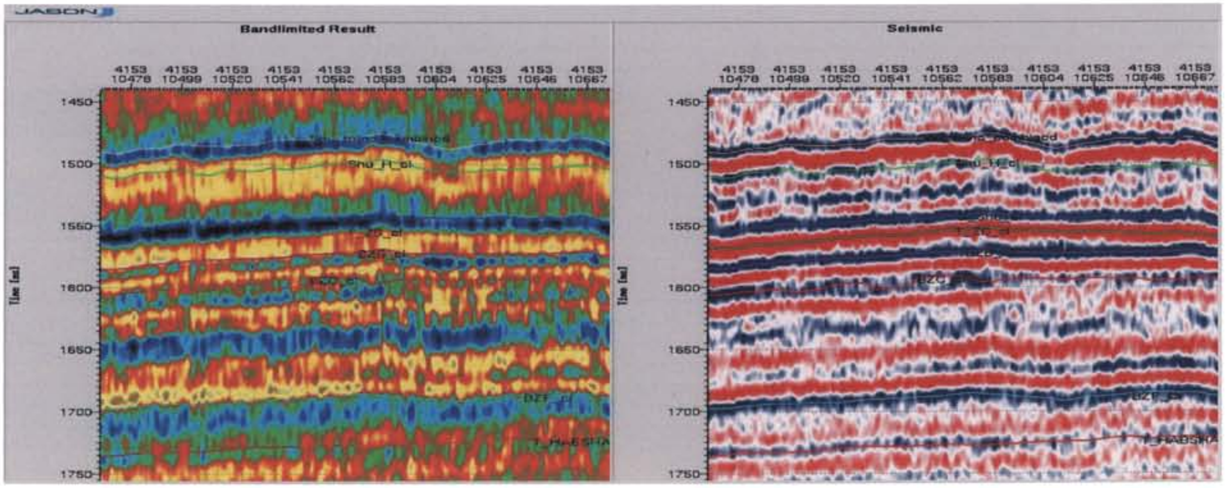

Figure 2. Horizons that follow reasonable seismic events on the right do not necessarily follow layer interfaces, more clearly seen in the inversion on the left. The inversion result was used to position horizons for a better structural model between wells.

Impedance inversion in carbonate environment

Good quality seismic data and a stable wavelet are an essential part of an inversion. If the inversion is performed properly, the result gives better amplitude information by minimizing tuning and side lobe interference effects. Because of the unique structural makeup of the northern part of the field, an innovative methodology was used to developed the low frequency AI model (log interpolated impedance earth model) to merge with the bandlimited seismic AI. A total AI estimate was derived from this merging process.

A more complex geologically correct impedance model, incorporating the known clinoform stratigraphy, allowed for the extraction of reservoir properties from thinner layers, resulting in more detailed attribute maps that will be ultimately used to help build the static model for reservoir simulation studies. Figure 4 is a representative example of the final porosity estimate from the total acoustic impedance inversion result.

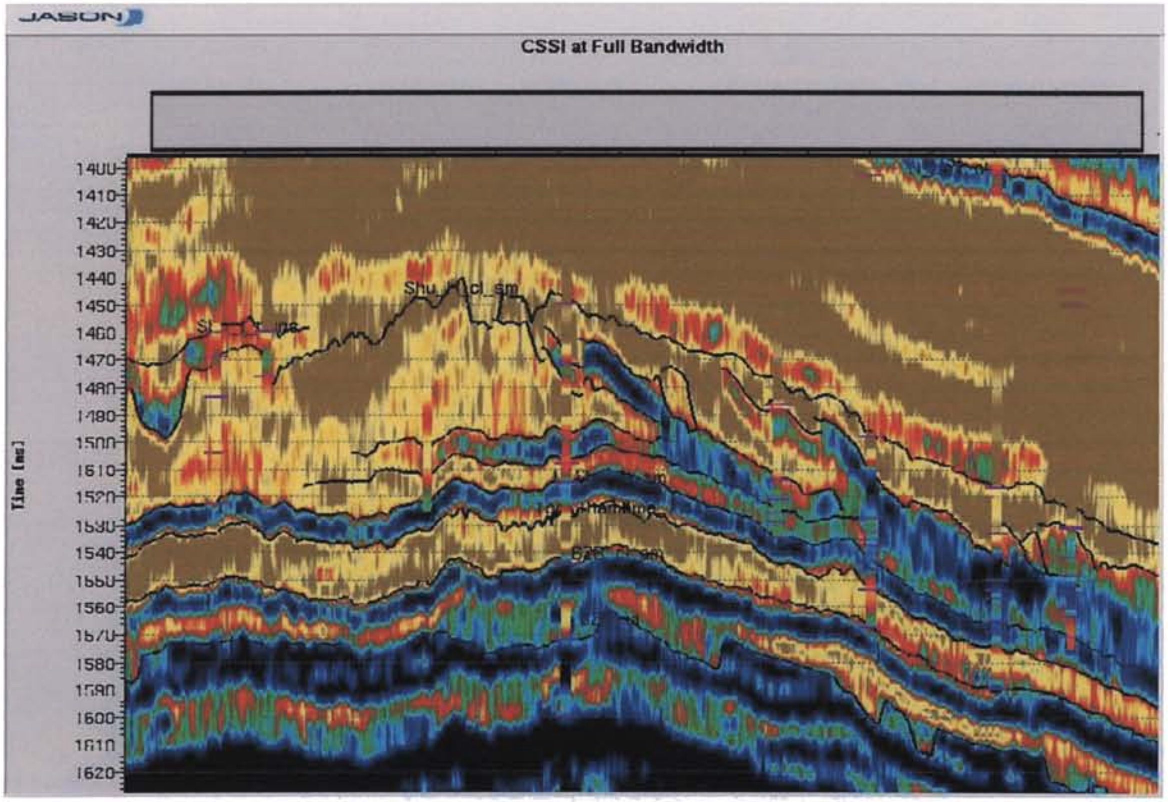

Figure 3. The structural framework with prograding clinoforms, and the low frequency earth model interpolated from the log information. High impedance is depicted by blues. Wells have been superposed with purple markers.

The relationship used to transform the total AI to porosity (Figure 5) was derived from the available well data and was found to be dependent upon reservoir rock type. The geologic information coupled with the sequence stratigraphy results allowed for the building and application of the proper AI-to-porosity relationships.

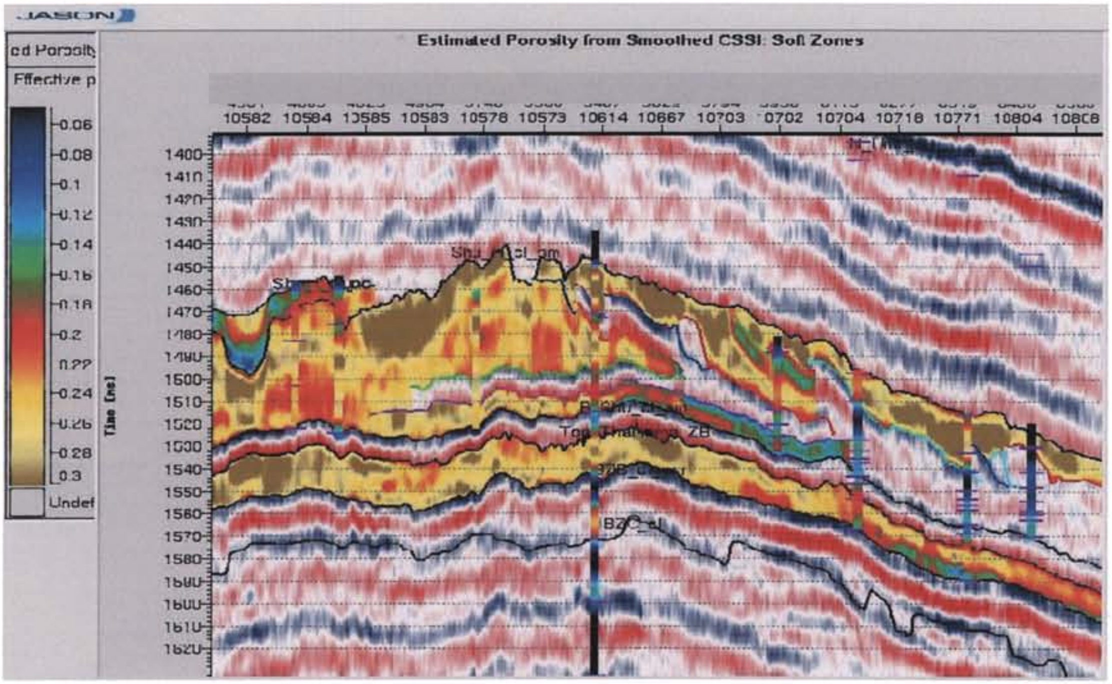

Figure 4. The final estimated Total Acoustic Impedance result. Wells have been superposed at seismic bandwidth for comparison. Higher AI layers are colored blue.

Conclusions

The results of this project added value in a number of ways including 1) improved structural definition of the field, 2) improved well ties to the seismic, 3) and a higher level of integration of all available data. The main objective of this project, however, was to provide improved reservoir properties such as porosity to build an improved static reservoir model. This objective was successfully achieved. The improved interpretation and porosity estimated from the inversion results will be used to build a reservoir static model that is closer to the true geology. The porosity from the AI will be used to populate the model between the available well control points. With improved reservoir simulations, the ultimate goal is to achieve efficient and cost effective recovery of the oil present in the field.

References

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