by ***D. H. Johnston, J. J. Shyeh, and J. E. Eastwood,***
ExxonMobil Upstream Research Co.; and
M. Khan, and L.R. Stanley,
Western Geophysical

Interpretation and Modeling of Time-Lapse Seismic Data: Lena Field, Gulf of Mexico

Abstract

Two 3D seismic data sets from the Lena Field, Gulf of Mexico, are analyzed for time-lapse effects. The seismic analysis involves cross equalization and residual migration of the post-stack seismic data, as well as full reprocessing and attribute analyses. The time-lapse differences for the B80 reservoir are compared with production data, geologic models, flow simulations, and forward seismic models. The time-lapse seismic difference anomaly is interpreted to be a region of gas invasion. Areas bypassed by the injected gas are identified from 4D seismic data as opportunities for infill drilling. Successful interpretation of this time-lapse seismic data illustrates the importance of integrating the results of modeling and simulation with seismic processing and interpretation.

Introduction

Seismic monitoring (time-lapse or 4D seismic) has the potential to significantly increase recovery in existing and new fields. One important issue is the significance of the seismic difference anomaly relative to nonrepeatable noise. While future field developments should benefit from seismic acquisition designed for time-lapse monitoring, current seismic monitoring opportunities consist of existing fields for which one or more 3D seismic surveys have already been acquired. The reliability of a 4D interpretation is measured by the repeatability and the reconciliation of the time-lapse anomaly with geologic and production data. The objective of this paper is to interpret the seismic difference observed in the Lena B80 reservoir through the use of geologic modeling, flow simulation, and seismic modeling.

B80 Reservoir and Production History

The Lena Field (Mississippi Canyon Block 281) is located south of the modern Mississippi delta in 1,000 feet of water. The field is situated on the western flank of a salt diapir within a fault-bounded intraslope basin. The B80 reservoir is located about 10,500 feet below sea level and is interpreted as a low-stand fan systems tract representing deposition in distributary lobes composed of amalgamated and channelized turbidites. The average total porosity of the B80 sands is 27% and the permeability ranges from 30-200 md. The average reservoir thickness is 100 feet with a net-to-gross of 47%.

Oil production in the B80 reservoir began in 1984. The B80 has been depleted by a combination of bottom water and gas-cap expansion drive, supplemented with up-dip gas injection. Pressure decline below the bubble is believed to have trapped about 5% gas in the entire oil leg. In 1987 gas injection was initiated just below the original gas-oil contact. Gas quickly broke through to producers resulting from gravity. By 1995, most down-structure wells had watered out and many producers had high GOR production.

Seismic Data

A preproduction 3D seismic survey was acquired over the Lena Field in 1983 and a regional 3D spec survey covering the field was acquired in 1995, after 11 years of production. The 1983 survey was acquired in an east-west direction and the 1995 survey was shot in a N58°E direction. Initial differences in the two seismic data volumes are substantial and are due primarily to different acquisition and processing parameters.

A stepwise approach was taken regarding the processing of the two data volumes. Post-stack reprocessing represents an inexpensive, rapid analysis technique, whereas reprocessing both data sets represents a more rigorous, expensive, and time-consuming methodology.

One of the obstacles to full reprocessing is that the navigation data for the 1983 data are unavailable. Navigation information

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was generated based on knowledge of the acquisition parameters, the final seismic grid, and observer's notes. The fidelity of the reprocessed volumes exceeds the original processing for both the 1983 and 1995 surveys, especially for steeply dipping reflectors at the salt flank.

For the relatively low-dip B80 reservoir, which is removed from the salt dome flank, the time-lapse difference anomaly is similar for each processing stream.

4D Difference and Interpretation

Differences of the 1995 and 1983 surveys are calculated from interpolated time-aligned seismic traces and illustrated in Figure 1. There is a large difference anomaly unambiguously associated with the B80 reservoir. The anomaly is restricted to the reservoir (outlined by the polygon). The difference is nearly zero away from the reservoir, demonstrating that the data are repeatable and that the seismic difference is significant.

Reservoir flow simulation and the 3D geologic model are used to generate a synthetic seismic difference volume. Petrophysical analyses based on sonic and density logs relate the reservoir properties in the geologic and simulation models to seismic properties. A comparison of the synthetic and actual seismic differences is used to facilitate the interpretation of reservoir changes imaged by 4D seismic data.

Geologic Models and Simulation

Geologic models of effective porosity and shale volume are initially constructed independently for each parasequence using Sequential Gaussian simulation. Because the reservoir is below seismically resolvable thickness, collocated cokriging with Bayesian updating is used to incorporate seismic amplitude attribute information in the geologic model. The seismic attribute is corrected for the effect of reservoir fluids using forward seismic modeling. The resulting reservoir flow model has a good match between the simulated and actual cumulative production history of the B80 reservoir.

Petrophysics

Petrophysical analysis shows that from 1983 to 1995 the original water leg sees a very slight increase in impedance because the formation fluid pressure has declined, increasing the effective stress on the reservoir. Where oil has been swept by water, the impedance is almost unchanged because of the compensating effects of trapped gas, water displacing oil, and pressure decline on the rock frame. In the remaining oil leg, the small decrease impedance is again the result of trapped gas competing with the effect of pressure. Impedance in the original gas cap increases as a result of pressure decline. The gas-invaded zone, originally the up-dip portion of the oil leg, has the largest impedance change.

Seismic Models

Synthetic 3D seismic volumes representative of the 1983 and 1995 reservoir conditions are derived from the geologic models, reservoir flow simulations, and petrophysical analysis. The most significant change in the seismic response between 1983 and 1995 occurs in the gas cap expansion or gas injection zone. The seismic difference anomaly in Figure 2 is located in the area invaded by gas and represents regions of significant gas saturation changes.

Interpretation

As shown in Figure 3, the anomaly is restricted to the central portion of the reservoir, suggesting that there may be regions of bypassed oil or areas not contacted by gas to the north and to the south. The area to the north may be an area of poor reservoir quality or an area swept by water as suggested by the flow simulation. Both conditions will result in little seismic change.

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Thus, an area of bypassed oil is identified to the south near the A29ST well. The interpretation is consistent with well production data.

Conclusions

Lena represents a significant challenge for the application of time-lapse seismic methodology. Even so, the time-lapse seismic analysis at Lena represents an important success. Post-stack processing and full reprocessing of the seismic data have shown that time-lapse differences in the B80 reservoir are distinct and robust. These differences are interpreted using reservoir simulation and forward seismic modeling to be the result of gas cap expansion and/or gas injection. By comparing measured time-lapse seismic differences with model predictions, areas bypassed by the injected gas can be identified. The identification of potentially bypassed oil may affect future drilling decisions.

Acknowledgment

We thank Exxon USA New Orleans Production Office for its support in this study.

Biographical Sketch

David H. Johnston is a Research Associate for the ExxonMobil Upstream Research Company (URC) in Houston, Texas. He received a BS degree in earth sciences from the Massachusetts Institute of Technology in 1973 and a PhD in geophysics in 1978, also from MIT. He joined Exxon in 1979 and has held assignments in rock physics research, velocity analysis, and seismic reservoir characterization. He is currently technical team leader for time-lapse seismic research and is responsible for the development and the world-wide application of the technology.

Dr. Johnston is active in the Society of Exploration Geophysicists (SEG) and the Society of Petroleum Engineers (SPE). He was Secretary/Treasurer of the SEG in 1990, Chairman of the Development and Production Geophysics Committee from 1987 to 1988, and Chairman of the Interpretation Committee from 1991 to 1992. He has served on SEG, SPE, and OTC technical program committees and was Technical Program Chairman for the 1988 SEG/CPS Conference in Daqing, China.

In addition to a number of published papers in *Geophysics* and other technical journals, Dr. Johnston was co-editor of the book *Reservoir Geophysics*, published by the SEG in 1992 and co-editor of the SEG Reprint Series volume on *Seismic Wave Attenuation* published in 1981. He has presented numerous papers on rock physics and reservoir geophysics including keynote addresses at several conferences. Dr. Johnston was awarded the Best Presentation by the SEG in 1993, was an SPE Distinguished Lecturer from 1992 to 1993, and an SEG Distinguished Lecturer in 1999. □

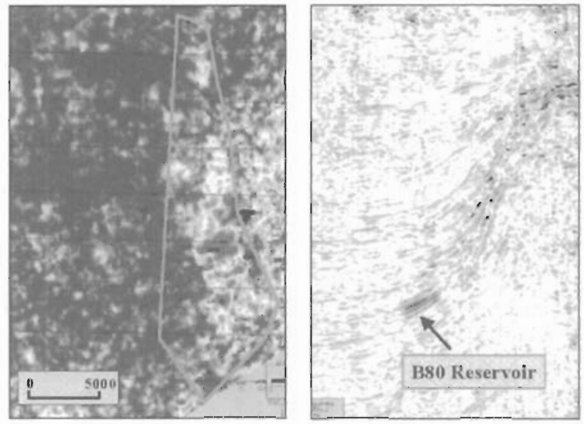

Figure 1. *Seismic difference volume. The average absolute amplitude map is calculated around the B80 reflection from the difference volume. The polygon outlines approximately the B80 reservoir.*

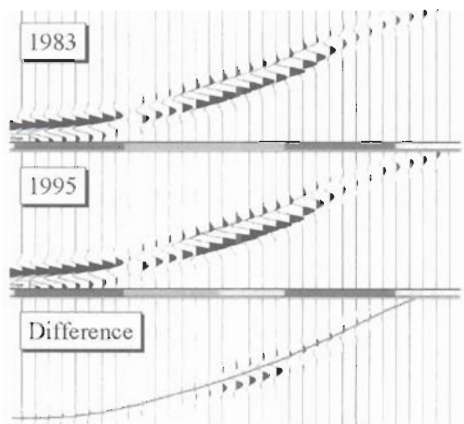

Figure 2. *Cross-sections from 1983, 1995, and difference seismic models. The greatest change occurs in the gas-invaded zone. The top B80 horizon time is shown by the line on the difference.*

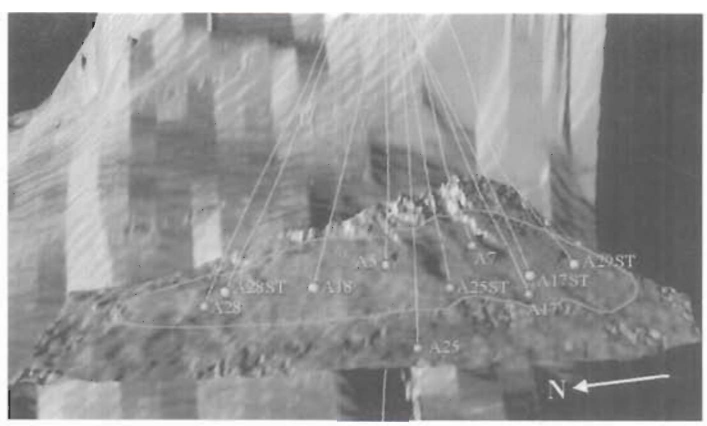

Figure 3. *3D visualization of the B80 seismic difference. Wells A28, A25, A17 have watered out, wells A5, A7, A25ST are gas injectors or producers, wells A28ST, A18, A17ST are oil producers and the well A29ST was lost during a workover in 1994.*