

Processing for robust time-lapse seismic analysis: Gulf of Mexico example, Lena Field

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Summary:

It is a conceptually simple process to compute differences between two 3D seismic monitoring surveys. However, interpretation of seismic differences in terms of reservoir changes during production assumes repeatability of the surveys. As a result, the naive application of this methodology can lead to erroneous results. Ross *et al.* (1996, 1997) discussed many of the problems associated with differences constructed from multiple 3D seismic data volumes. Most problematic are the issues concerning legacy time-lapse data, where the least number of experimental controls are in place. The purpose of our study was to assess the impact of different processing efforts on two legacy data volumes and report the results in terms of not only repeatability but also the impact on the final time-lapse interpretation in the reservoir interval.

Introduction:

Seismic monitoring (time-lapse seismic) has the potential to significantly increase recovery in existing and new fields. However, there are many issues associated with the application of time-lapse seismic data. Two of the most significant are repeatability of the seismic data in non-reservoir portion of the data volume, and the robustness and credibility of the seismic difference anomaly within the reservoir.

While future field developments should benefit from improvements in seismic monitoring and acquisition technology over the next decade, the portfolio of current seismic monitoring opportunities for most companies consists of existing fields for which one or more 3D seismic surveys have already been acquired. These legacy seismic data sets were not acquired for the purposes of seismic monitoring and are often different in terms of acquisition and processing parameters. In addition, their acquisition is rarely timed to optimally map reservoir changes or impact development decisions.

Seismic repeatability is sufficient for time-lapse interpretation if the seismic differences in the region of interest are substantially greater than the differences outside the region of interest. The smaller the change in the seismic response due to production, the greater the repeatability required of the seismic data. Seismic modeling incorporating rock physics and reservoir simulation can help estimate the magnitude of reservoir changes but repeatability and interpretability can only be determined by the analysis of multiple seismic surveys.

To better understand the magnitude of the processing effort required to obtain acceptable differences, we have chosen data acquired over the Lena Field in the Gulf of Mexico. We sequentially increase the level of sophistication of the seismic processing effort, quantifying and reporting the results at each step. Exxon acquired the baseline survey at Lena prior to production in 1983. The monitor survey is part of a regional spec 3D seismic survey shot by Western Geophysical in 1995.

Differences in the two seismic data volumes are substantial and are primarily due to differences in the acquisition and processing parameters as apparent from an average absolute amplitude calculation over a two second window encompassing the reservoir interval (Figure 1).

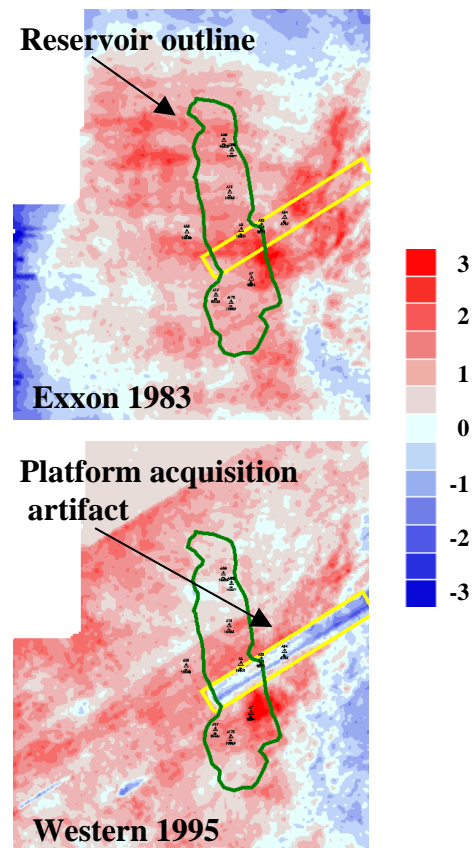


Figure 1: Plan view map illustrating acquisition artifacts from both surveys. Maps plot average absolute amplitude (standard deviations about the mean) for a two-second window

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The Exxon 1983 data shows amplitude artifacts associated with acquisition along the east west direction whereas the Western 1995 survey shows a very pronounced acquisition artifact in the north east - south west direction. As well a polygon is outlined on both maps indicating a low fold low amplitude artifact associated with the offshore platform for the 1995 Western survey.

Field Description

Geologic Setting

The Lena Field (Mississippi Canyon Block 281) is located 5 miles south of the modern Mississippi delta in 1,000 feet of water. The field is situated on the western flank of a salt dome within a fault-bounded intraslope basin. Hydrocarbon production is from six Pliocene-age sands, the deepest of which (B80) is the subject of this study.

The B80 reservoir is located about 10,000 feet below SL at about 3 sec seismic TWT. The interval is interpreted as a low-stand fan systems tract representing deposition in distributary lobes composed of amalgamated and channelized turbidities. The updip limit of the sands lies about 2,000 feet west of the salt flank and the reservoir thickens basin-ward to the west. The average porosity of the B80 is 27% and the permeability ranges from 30-200 md. The gross average reservoir thickness is 100 feet with a net-to-gross of 47%.

B80 Production History

Oil production in the B80 began in 1987. The reservoir has been depleted by a combination water drive and gas cap expansion supplemented by gas injection. The reservoir pressure was initially 5,000 psi and is now about 3,500 psi, near the bubble point. Numerous down structure wells have watered out and also have high GOR production from over running in the low dip beds of this reservoir.

Seismic Data

A pre-production 3D seismic survey over the Lena Field was acquired by Exxon in 1983. It was shot with a single source and a single 3000 m streamer. The field bin size is 12.5x50 m with 60 fold. Western Geophysical acquired a regional 3D spec survey covering the Lena Field in 1995, after 8 years of production. The survey was shot with dual sources and dual 4,000 m streamers. The field bin size is 12.5x40 m with 52 fold. The 1983 survey was shot in an east-west direction and the 1995 survey was acquired in a N58°E direction. The majority of the reservoir is at tuning frequency with an average isochron of 25 ms.

Processing Scenarios

A stepwise approach was taken regarding the processing of the two data volumes. The processing strategy was separated into two distinct stages relating to the degree of sophistication of the processes. The first stage represents a less expensive rapid analysis methodology, while the second stage represents a more rigorous, expensive, and time-consuming methodology. Prior to analysis in the first stage, the Western 1995 3D vol-

ume was re-gridded to be coincident with the Exxon 1993 3D volume.

Stage 1: Post Stack - Post Migration

1. Global cross equalization
2. Global cross equalization + long window trace amplitude equalization
3. Long window trace amplitude equalization + Global Weiner-Levinson filtering
4. Long window trace amplitude equalization + Global Weiner-Levinson filtering + local event alignment
5. Spatially variant Weiner-Levinson filtering
6. Reverse migration - global Weiner-Levinson filtering - migration

The long window trace equalization between surveys is a necessary step to provide amplitude consistency between the two surveys since marked differences were observed during the initial quality control analysis of the data sets. The single match filter for steps 3 and 4 was designed over a sub-volume of the survey composed of 5,000 traces down dip and above the B80 reservoir. The dip of the reflectors in this portion of the section is only a few degrees. Prior to the match filter calculation, the events in the analysis window were aligned between surveys to remove time shifts. A match filter was designed for each trace pair between surveys and then averaged to create a single filter operator. The characteristics of this single filter, convolved with the 1995 data set, are shown in Figure 2.

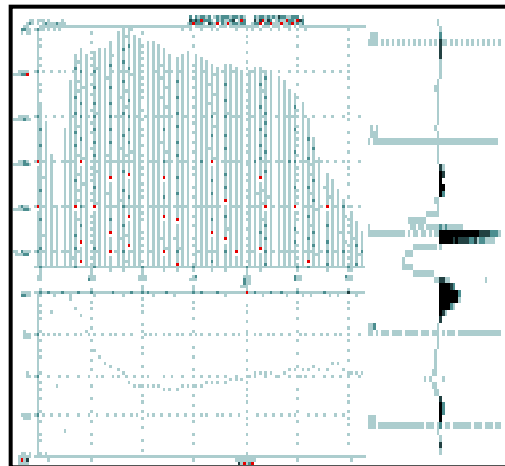


Figure 2: Weiner-Levinson match filter derived from sub volumes of the two 3D surveys.

Stage 2: Remigration and Pre-stack analysis

1. Migrate both data sets using the same velocity, aperture, and algorithm
2. Process both surveys with consistent statics, wavelet processing, amplitude handling and velocities. Design, quantify, and apply cross equalization filters. Time migrate with identical algorithm, aperture, and velocity field

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Discussion of Results/Conclusions

For each processing scenario the differences are calculated for both the reservoir zone (relative to the seismic reservoir horizon) and for the seismic volume in the vicinity of the reservoir. It was found that the largest incremental improvement in stage 1 was achieved with the application of global Weiner-Levinson filtering, long window trace equalization and local event alignment.

Differences in the migration velocities and migration algorithms applied to each survey result in events with the same true dip not being positioned identically in the two volumes. This problem is immediately apparent from the difference volume calculated by subtracting the 1995 survey from the 1983 survey subsequent to step 4 in the processing sequence for stage 1 (Figure 3). The difference amplitudes in the shallow dipping portions of the survey have been reduced 5-10 db relative to the amplitudes in the two original 3D surveys. However, as the event dip steepens, the residual difference amplitude magnitude increases significantly. Thus, this is an unsatisfactory result, since there are differences outside the reservoir, which are as significant as those contained within the reservoir.

Partial compensation for this problem was addressed by aligning pairs of traces from the two seismic volumes to maximize their cross correlation as determined from a moving window. As a result of this process, a new series of attributes are calculated for every time sample in the seismic volumes. Within the moving window, the cross correlation is calculated between corresponding traces over a range of allowable time lags. For the maximum correlation, the time lag, the trace sample difference, and the correlation value are recorded in new 3D data volumes (Figure 4). In Figure 4 the amplitude response coincident with the B80 reservoir is unambiguously distinguished from the background difference. This methodology is a natural extension of analysis techniques discussed by Schmitt *et al.* (1995) and Pepper *et al.* (1997). These new data volumes quantify the repeatability, partially compensate for the migration discrepancies and most importantly define a new set of seismic attributes for the analysis of time-lapse differences. An interval attribute (average absolute amplitude) was extracted along the B80 horizon in the difference volume. Figure 5 shows that the amplitude brightening within the reservoir is significantly greater than the background noise.

For the B80 reservoir (which has an average dip of 20°) the range of time lags to maximize correlation was 10 - 50 ms, with the magnitude of correction increasing as the reservoir dip increased. This implies that the spatial positioning of these dipping reflectors in the independently migrated data volumes are also not aligned by as much as several seismic bins in the dip direction. This problem is best addressed by re-migrating both data sets with the same migration velocity field and algorithm in the second stage of our study.

Acknowledgements

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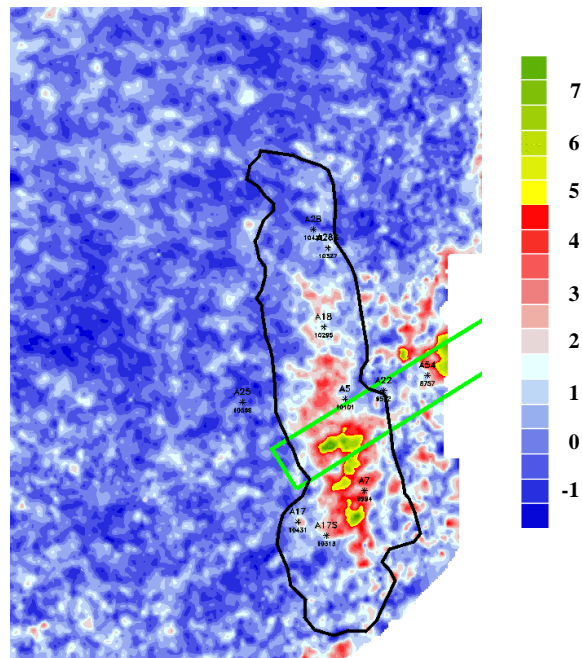


Figure 5: Interval amplitude difference for the reservoir horizon (150 ms window) after trace equalization and global Weiner-Levinson filtering

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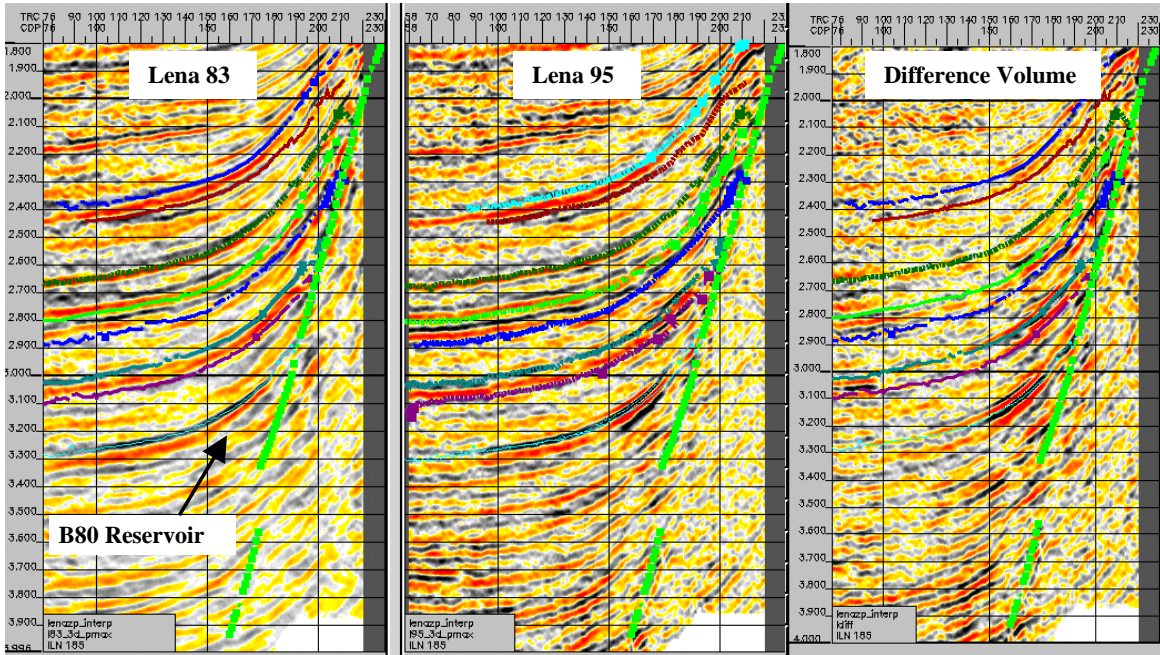


Figure 3: Representative cross section for seismic surveys after match filtering. Large differences are observable for the dipping reflectors.

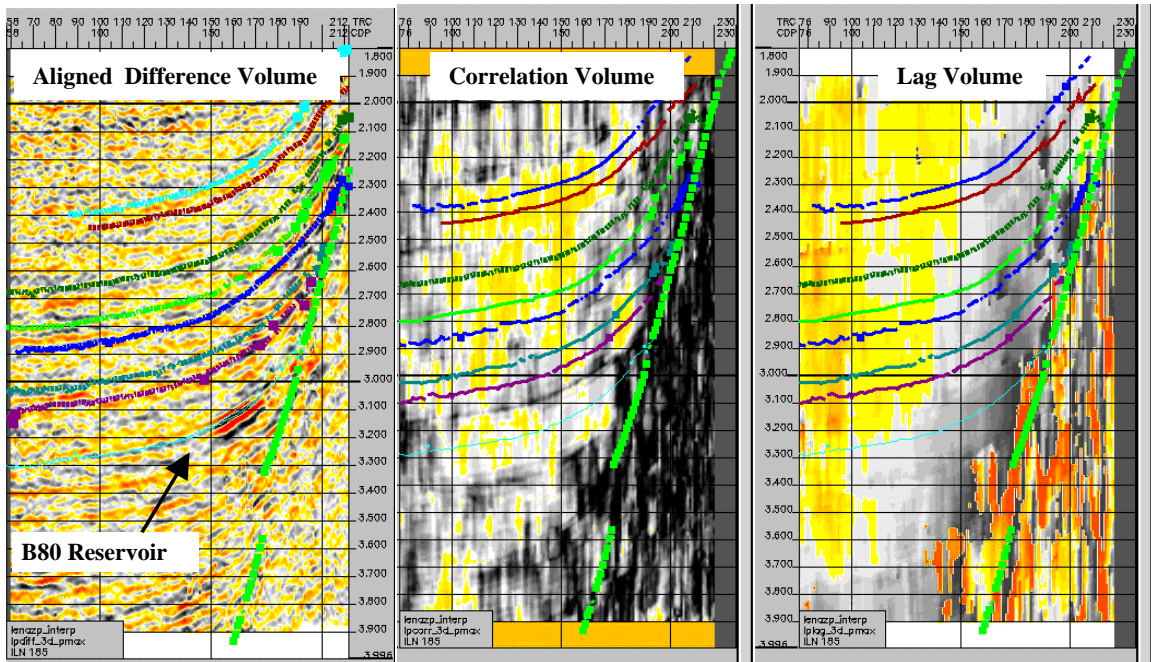


Figure 4: 4D seismic attributes based on local event alignment. A significant residual amplitude anomaly associated with the B80 reservoir is apparent.