A workflow for time-lapse seismic data conditioning for geophysical interpretation

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Abstract

The oil and gas industry is concentrating efforts and heavily investing in actions that increase the reservoirs' recovery factor. Time-lapse seismic analysis is a very important part of this effort because it enables improved understanding of evaluating the dynamic reservoir behavior. This work presents a workflow of time-lapse seismic data conditioning in the seismic interpretation environment, where prior seismic vintage and the most recent seismic vintage are reconciled to consistent amplitude and frequency level. (RICKETT and LUMLEY, 2001)Time-shifts between the seismic vintages are calculated and applied to the base volume. The results of the workflow are seismic volumes that may be used to initiate the multi-vintage time-lapse interpretation process. The source of the seismic data is shallow water field in the Gulf of Mexico.

Introduction

The time-lapse seismic or 4D seismic, as it is popularly known, has become a crucial tool for the integrated management of reservoirs. For instance, by analyzing the 4D data correctly, the movement of fluids can be defined within a reservoir, anisotropy of permeability and fluid flow can be identified, the process of field depletion can be understood, and can enable the determination of sub-seismic resolution features. (LANDRO, 2015).

Currently, there are many ongoing projects that incorporate time-lapse seismic processes, where the time-lapse seismic is acquired and processed for improved asset management. However, there are also many cases where two or more different 3D surveys can be used to extract information from the dynamic reservoir. Therefore, it is not common to perform time-lapse calculations in the interpretation environment.

The objective of this work is to show a time-lapse data conditioning workflow in a seismic interpretation environment. This workflow involves applying basic seismic processing then performing data normalization before performing the actual time-lapse interpretation process. It can be applied to both types of data, the data specifically acquired and used in multi-vintage processing for 4D analysis and the legacy data, which is a collection of different 3D surveys for which 4D analysis was not planned.

Method

Assuming that all seismic data is sampled from the same survey grid, the conditioning of seismic volumes is basically performed in four main steps, as shown in Figure 1.

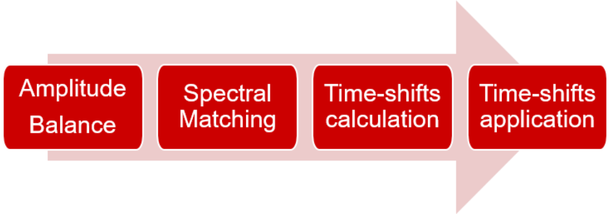

Figure 1: *Main steps of the 4D conditioning workflow.*

The amplitude balance process consists of adjusting the seismic volumes, base and monitor to the same amplitude level based on a common root means square (RMS) energy.

The spectral matching process is responsible for matching the multi-vintage seismic to same range of frequency content by tuning each trace spectrum to an average spectrum of the full seismic data.

The time-shift process has two stages: first, the process of computing the time-shifts, calculated trace by trace, is to find the lag $\Delta\tau$ which gives the highest cross correlation between signals in the calculation window [see equation (1) of Appendix]. The second stage is to apply the lag to the monitor trace, optimally shifting it so that it is aligned with the corresponding base trace.

The conventional quality controls, normalized root means square (*NRMS)* and *predictability,* are calculated before and after the application of the entire workflow to ensure that the results are coherent. The equations for their calculation were based on KRAGH and CHRISTIE (2002) and they are presented in the Appendix [equations (3) and (4)].

Results

The seismic data are from the shallow water Teal South petroleum field in the Gulf of Mexico. The base seismic data was obtained by conventional marine streamer acquisition and the monitor data was acquired by an ocean bottom cable (OBC) acquisition (ROCHE et. al, 1999). Both seismic volumes are the outcome of a pre-stack time migration (PSTM) processing. Figures 2 and 3, respectively, present the results before and after the application of amplitude balance and spectral matching.

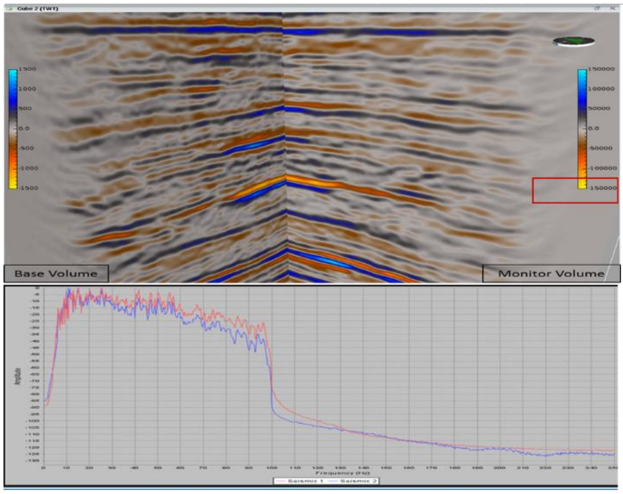

Figure 2: *Base (left) and monitor (right) seismic section of volumes before the application amplitude balance and spectral matching. The average spectra of both data (base in red and monitor in blue) are shown in the lower section of the figure.*

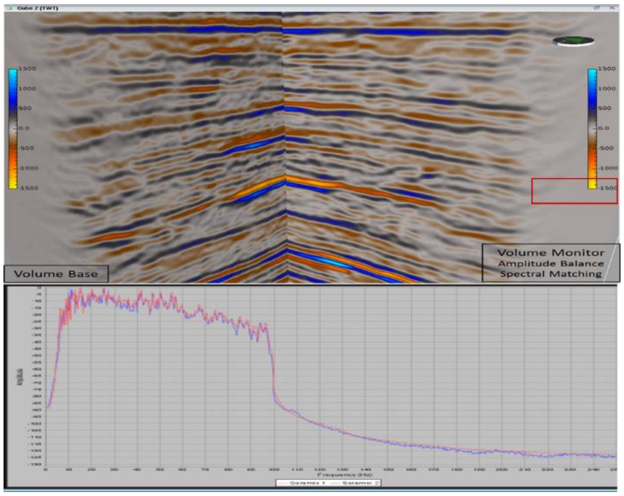

Figure 3: *Base (left) and monitor (right) seismic section volumes after the application amplitude balance and spectral matching. The average spectra of both data (base in red and monitor in blue) are shown in the lower section of the figure.*

By analyzing Figures 2 and 3, it is clear that the amplitude balance and spectral matching processes delivered the expected results. In Figure 2, the amplitude scale and the frequency spectrum differ but in Figure 3, after amplitude balance and spectral matching applications, the volumes match. The next step is to calculate the time-shift cube between base and monitor seismic volumes. The results are presented in Figure 4.

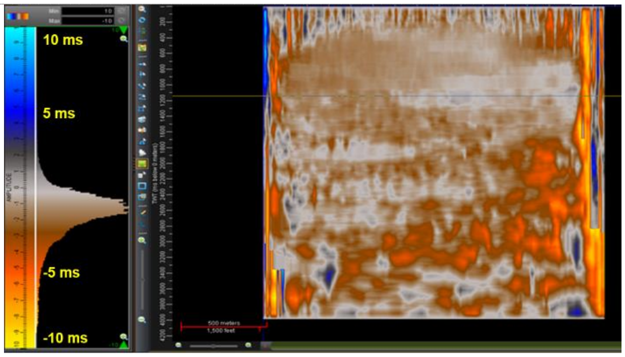

Figure 4: *Calculated time-shift volume (2D view).*

The time-shift volume demonstrates the manifestation of some large magnitude time-shifts reaching up to eight milliseconds. Such time-shift values could be expected, due to production-related effects, for example. Figures 5 and 6, respectively, present the results before and after the application of time-shift values in the base volume.

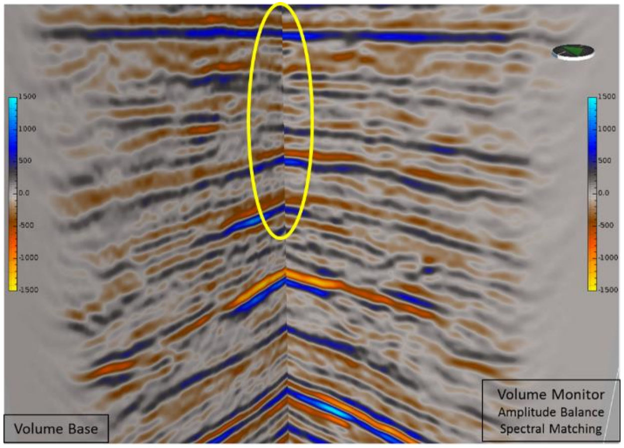

Figure 5*: Base (left) and monitor (right) volumes before application of time-shift values in base volume.*

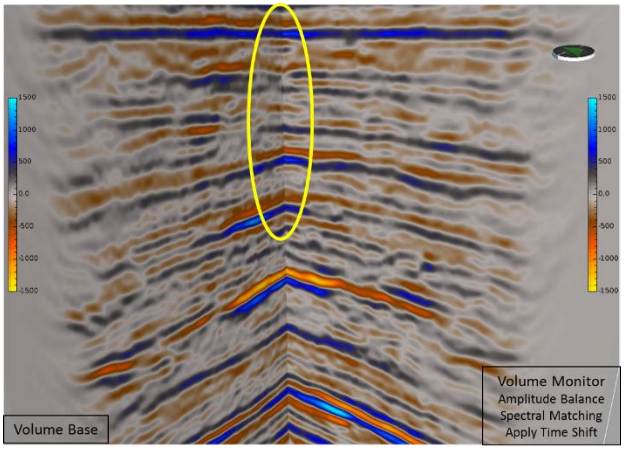

Figure 6: *Base (left) and monitor (right) volumes after application of time-shift values in base volume.*

In order to simplify the analysis of the results a yellow ellipse is drawn on Figures 5 and 6. It is relatively easy to realize the shifts in the seismic. Before the time-shift application in Figure 5, the seismic layers in the comparison zone are not aligned, i.e., do not occur at corresponding two-way time intervals, but after applying the time-shifts in Figure 6, the alignment of seismic reflectors has improved.

Before and after completing the entire workflow, the conventional quality control, *NRMS*, and predictability volumes are generated. The results are presented in Figures 7 and 8.

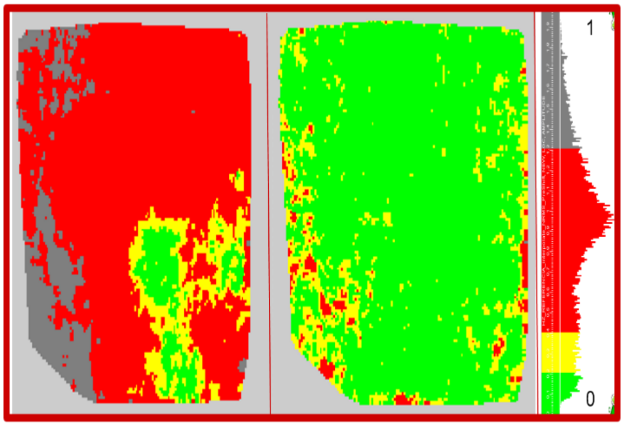

Figure 7: *Time slice of the NRMS quality control , before (left) and after (right) the workflow application.*

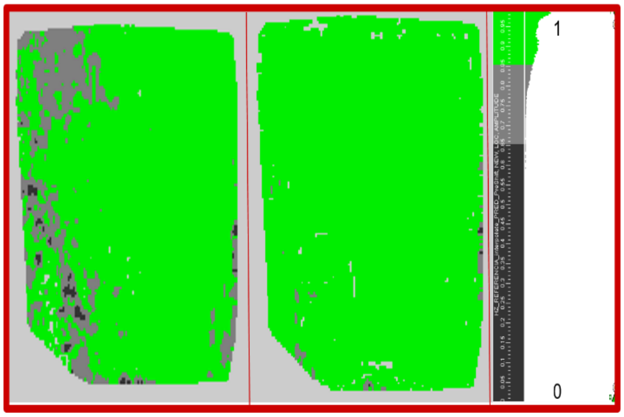

Figure 8: *Time slice of the Predictability quality control, before (left) and after (right) the workflow application.*

As anticipated, the results of the workflow demonstrate the values for *NRMS* close to a value of zero and values of *predictability* close to a value of one. Figure 9 illustrates the expected results for the respective cross plots of *NRMS* and *predictability*, (KRAGH and CHRISTIE, 2002).

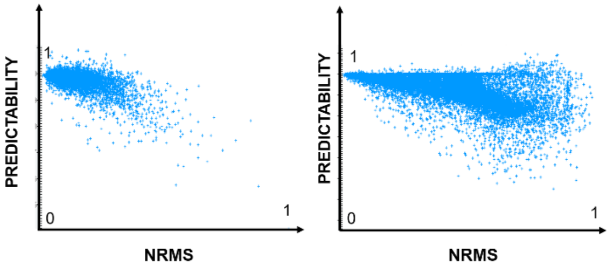

Figure 9*: Cross plots of the conventional quality controls volumes, NRMS and predictability, before (left) and after (right) the workflow application.*

Conclusions

Time-lapse seismic analysis has become increasingly valuable in the oil and gas industry during the past several years as investment in new research, technology and multi-disciplinary collaboration to increase the reservoir recovery factor have advanced. A substantial component of this objective is improved understanding of the reservoir behavior over time, and the time-lapse seismic analysis significantly contributes to reaching this objective.

This work demonstrates a workflow related to the equalization of seismic volumes in an interpretation environment. The seismic data is from a shallow water field in the Gulf of Mexico, where the base and monitor data were acquired by streamers and OBC, respectively. After this time-lapse equalization, the time-lapse seismic data may be analyzed to determine the presence of seismic anomalies, as well as used for seismic-driven history matching and confirming anomaly detection in the results for the flow simulator.

The completed workflow reached the expected results as appreciable equalization of the multi-vintage seismic volumes incorporating time-shifts was achieved. The generation and analysis of the examined quality controls, specifically *NRMS* and predictability, reinforce the value that the seismic equalization yields in the execution of time-lapse seismic data conditioning.

Acknowledgments

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Appendix

The time shift can be mathematically described as the lag $\Delta\tau$ between two temporal series):

$$\Delta\boldsymbol{\tau} = \underset{\boldsymbol{\tau}}{\mathbf{argmax}}\left(\int_{-\infty}^{\infty} \boldsymbol{g(t)f(\tau - t)dt}\right) \tag{1}$$

where $g(t)$ and $f(t)$ are the seismic traces (HALE, 2006). The NRMS is expressed as:

$$\boldsymbol{NRMS} = \frac{\mathbf{200} \times \mathbf{RMS}(\boldsymbol{a_t} - \boldsymbol{b_t})}{\boldsymbol{RMS}(\boldsymbol{a_t}) + \boldsymbol{RMS}(\boldsymbol{b_t})}, \tag{2}$$

where RMS is the Root Mean Square, given by

$$\boldsymbol{RMS}(\boldsymbol{x_t}) = \sqrt{\frac{\sum_{t_1}^{t_2}(\boldsymbol{x_t})^2}{\boldsymbol{N}}}, \tag{3}$$

and a_t and b_t are the base and monitor traces and N is the number of samples in the time interval $t_1 - t_2$. For the NRMS computation, the window size is the only required parameter. The predictability is expressed as:

$$\boldsymbol{PRED} = \frac{\sum \Phi_{\boldsymbol{ab}}(\boldsymbol{\tau}) \times \Phi_{\boldsymbol{ab}}(\boldsymbol{\tau})}{\sum \Phi_{\boldsymbol{aa}}(\boldsymbol{\tau}) \times \Phi_{\boldsymbol{bb}}(\boldsymbol{\tau})}, \tag{4}$$

where Φ_{ab} is the cross-correlation between traces a_t and b_t computed in time window $t_1 - t_2$.