Improving 4D Seismic Imaging by Modifying Baseline Depth Migration Velocity Model

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SUMMARY

One of the critical components for a successful 4D seismic project is to maximize imaging repeatability between the different seismic vintages in seismic processing by the use of same seismic processing flows and parameters, including the migration velocity model. There are examples that significant velocity changes in shallow reservoirs occur between surveys, leading to the degradation in 4D imaging repeatability and consequently uncertainties in the 4D seismic interpretation for the underlying reservoirs. A recent 4D project in West Africa is such an example where increases in gas saturation in the shallow reservoir due to production resulted in velocity changes up to 10% between baseline and monitor surveys. To mitigate this problem, we derived the needed migration velocity modifications by converting time shift data into relative velocity change estimates. The perturbed velocity model is then used to re-migrate the monitor seismic; the results are surprisingly effective. This paper will describe and discuss the observations, work processes, and the results from the application of this technique. Some possible applications of this technique to future 4D seismic projects are (1) significant localized overburden time-strain caused by pressure changes in the reservoirs, and (2) gas exsolution or gas migration.

Introduction

4D seismic, by taking seismic surveys at different times before (baseline survey) and after (monitor survey) hydrocarbon production (Figure 1), provides effective means for field-scale surveillance of the producing hydrocarbon reservoirs. Successful applications of this technology have been demonstrated to improve reservoir characterization, identify reservoir compartmentalization and permeability pathways, locate bypassed and un-drained reserves, and optimize infill well locations and flood patterns.

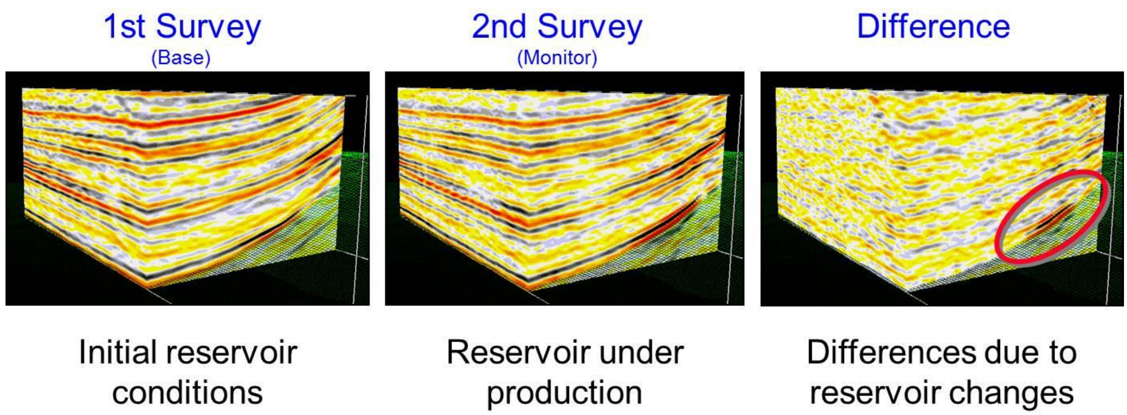
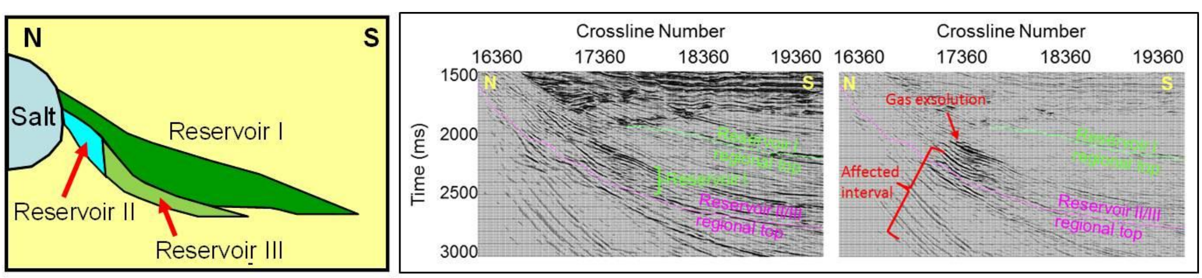


Figure 1. 4D seismic illustration.

Traditionally, 4D seismic data are processed and analyzed in the time domain. Most of the 4D projects were only time-migrated as of today. As technology for depth migration matures and amplitude fidelity of the depth migrated seismic data increases, more and more 4D projects employ depth migration technology for better imaging and positioning of the reservoir events. It has been noticed that there are situations that significant velocity changes can occur between baseline and monitor surveys in the subsurface; attempts and tests have been made to derive a perturbed velocity model for the migration of the monitor seismic data. However, few production scale processing examples with effective results exist in the literature.

Recently, a 4D project from West Africa was executed. Figure 2a shows the schematic of the main reservoir units. Increases in gas saturation lead to significant velocity changes in the shallow reservoir (Reservoir I, Figure 2a) between surveys. As a consequence of these significant velocity changes, large time shifts are induced between the seismic reflection events of the baseline survey and those of the monitor survey, causing imaging repeatability problems and uncertainties in the 4D seismic interpretation for the underlying reservoirs (Reservoir II and Reservoir III). Migrating the baseline and monitor data with the same velocity model was found to be inadequate (Figure 2b and Figure 2c).



(a) (b) (c)

Figure 2. (a) Schematic of reservoir cross section. (b) Example baseline seismic cross-section. (c) Example difference seismic cross-section when both baseline and monitor seismic data were migrated with baseline velocity model.

To address this problem, a team of seismic processors, interpreters, and 4D geophysics application experts worked collaboratively to develop, test, and implement a work process so that modifications to the depth migration velocity model between baseline and monitor times are made to produce effective results that are used for infill well placement interpretation. This paper will describe and discuss the observations, work processes, and the results from the application of this technique.

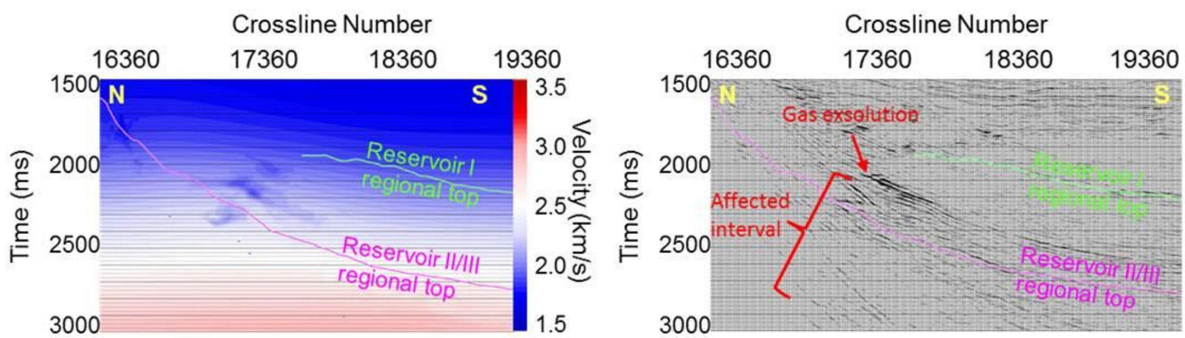
Method and/or Theory

To account for the effect of gas exsolution and gas injection on the migration velocity model, the baseline velocity model was perturbed with the following procedures to derive the velocity model to migrate the monitor data:

1. Perform PSDM to both baseline and monitor seismic data using the baseline velocity model.
2. Compute time shift by time alignment of monitor and baseline seismic data
3. Convert time shift data to relative velocity changes (dVV) using the algorithm outlined in Chu (2011).
4. Scaled the baseline velocity model with a scalar volume derived directly from dVV data – dVV geobody perturbed velocity model or geobody perturbed velocity model.
5. Migrate the monitor seismic data with the geobody perturbed velocity model

Examples

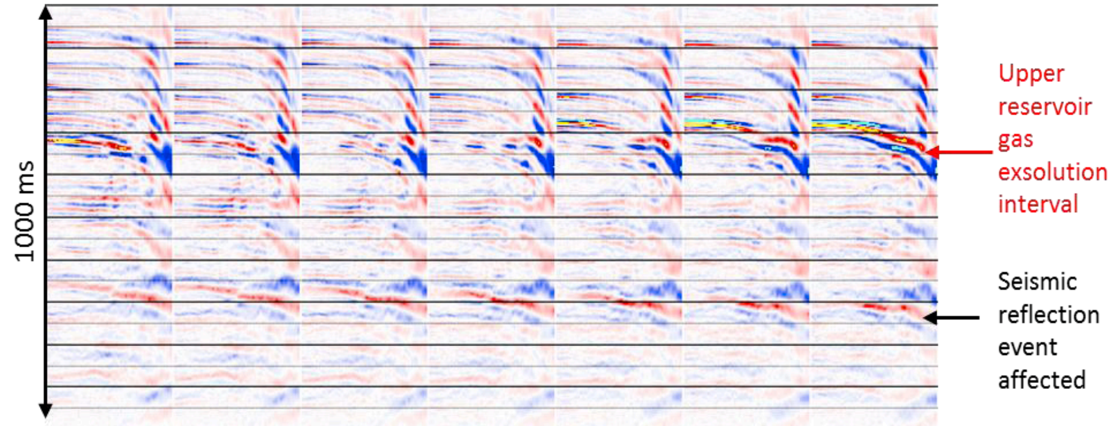
Figure 3a shows a cross-section through the geobody perturbed velocity model. The average change in the velocity is about 3% with local maxima at about 10%. No further smoothing was performed on the velocity model. Figure 3b shows the results from the geobody perturbed velocity model migration. Comparing to the results from a single velocity model migration (Figure 2c vs. Figure 3b), the “sag” due to gas exsolution in the monitor data migrated with the geobody perturbed velocity model has been corrected: much of the residual amplitude differences between the monitor and baseline seismic has been removed without cross-correlation time shifts; confidence on the difference amplitude below the gas exsolution interval being real 4D signal is increased.



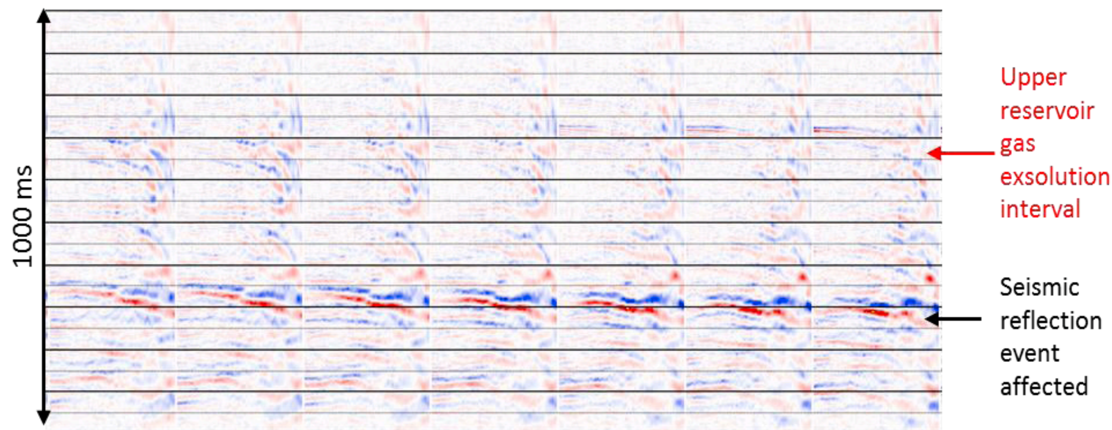
(a) *(b)*

Figure 3. (a) dVV geobody perturbed velocity model. (b) Cross-section of difference seismic data: monitor seismic has been migrated with the dVV geobody perturbed velocity model.

Further validation and benefits of migrating monitor seismic with dVV geobody perturbed velocity model are shown by examining the migrated gathers. Figure 4 and Figure 5 compare the monitor gathers migrated with baseline velocity model (Figure 4) and the same gathers migrated with the perturbed velocity model (Figure 5). In Figure 4a, the seismic reflection event pointed to by the black arrow is slightly under-corrected, resulting in the large 4D difference that is due to offset-dependent timing mismatch between monitor and baseline (Figure 4b). With the same monitor gathers migrated with the perturbed velocity model, the seismic reflection event becomes flatter (Figure 5a) and the offset-dependent timing mismatch is largely removed (Figure 5b).



(a)



(b)

Figure 4. Examples of (a) monitor seismic gather data migrated with baseline velocity model and (b) the corresponding difference between monitor and baseline.

Conclusions

The examples shown above illustrate that in 4D seismic projects, production induced velocity change in the reservoir interval can degrade 4D seismic repeatability in the interval below. Under-corrected seismic reflection events below a gas exsolution interval cause offset-dependent event timing mismatch between monitor and baseline; this timing mismatch can lead to biases in the stacked 4D seismic amplitude difference and cannot be corrected by post-stack time shift alignment. A technique has been developed to perturbed baseline velocity model over the reservoir interval based on the time shift data. This perturbed velocity model was used to migrate monitor seismic data in the depth domain; the results are shown to be effective both by the removal of time "sag" on the stack section and by the removal of residual 4D amplitude difference artifact between monitor and baseline due to offset-dependent timing mismatch of seismic reflections.

A major limitation in the current technique is the 1D assumption in calculating the relative velocity change because the technique is based on trace-by-trace 1D cross-correlation time shifts between monitor and baseline. Other more sophisticated but computationally intensive methods involving full waveform inversion may lead to further improvement over the current technique (Partha et al., 2012).

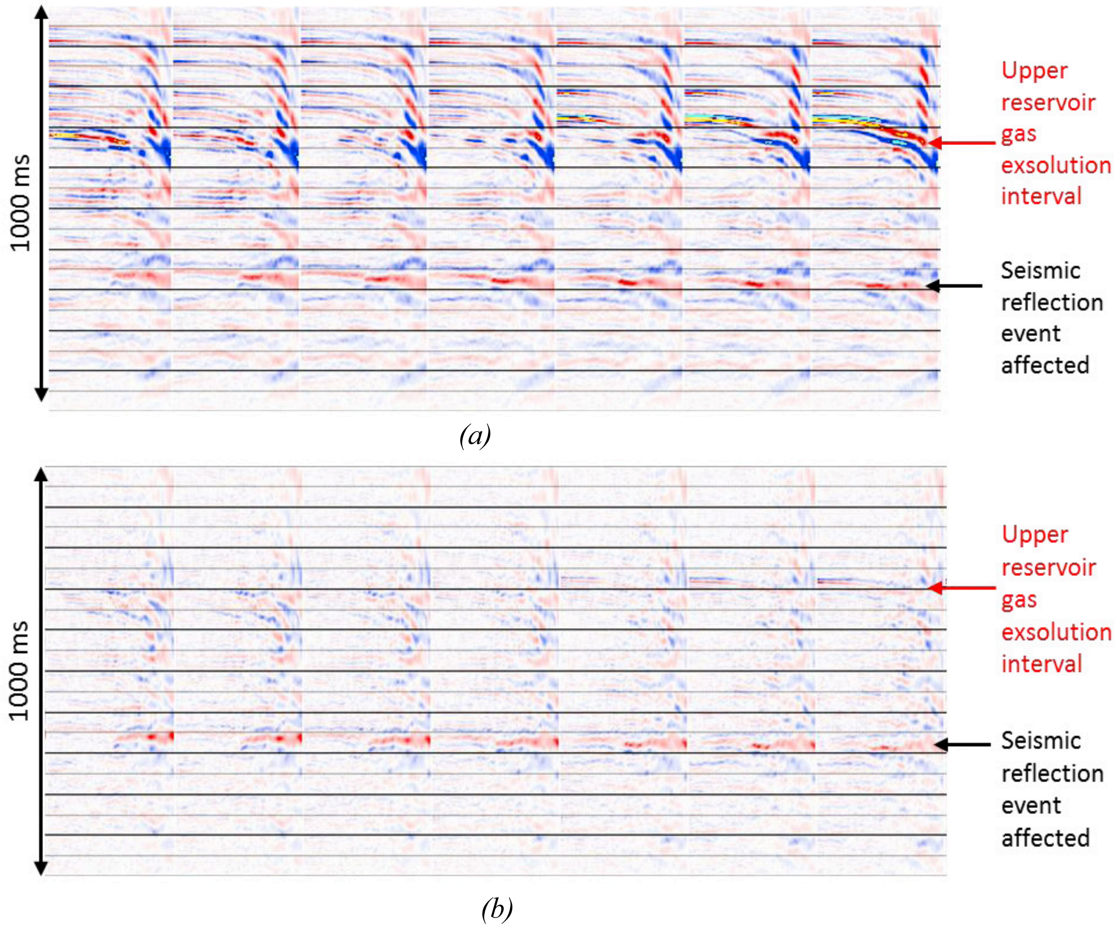


Figure 5. Examples of (a) monitor seismic gather data migrated with baseline velocity model and (b) the corresponding difference between monitor and baseline.

Acknowledgements

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