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A 4D Seismic Processing Case Study in a Difficult Shallow Offshore Complex Carbonate Field.

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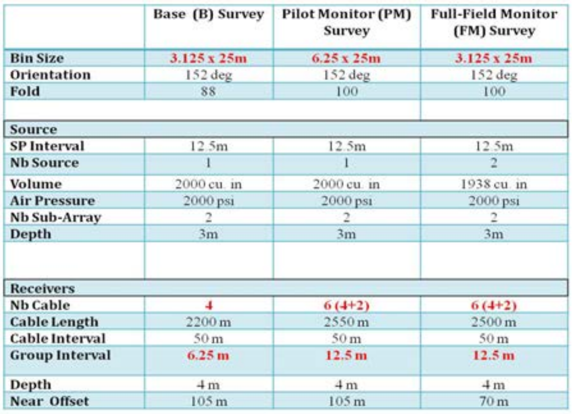
Summary

Time-lapse seismic processing in carbonate fields having complex geology and in difficult seismic contexts requires highly specialized teams for success. Our field case has a flat structure, a poorly-imaged but highly reflective sea bottom and is covered by towed-streamer data in about 60m of water depth. Multiples contamination is severe and these are coherent with primaries. We tested several 4D seismic processing routes using a base and two monitor surveys and have summed up our experiences in four learning points: A simplified targeted demultiple flow avoiding adaptive methods improves 4D metrics better than a complicated one. A guided co-denoise technique using base and monitor vintages attenuate non-repeated noise from data while preserving 4D timeshifts and 4D amplitude changes. A mute design optimization prior to stack attenuates residual multiples that degrade 4D signal. Finally, seismic acquisition parameters have a strong impact on computed 4D seismic attributes even if this may not be the case in 3D. These learning points coupled with multidisciplinary interactions and an iterative processing QC strategy assure the delivery of data with a more interpretable 4D signal that permit the delineation of depleted zones, flushed zones and by-passed oil for future infill-well drilling and optimal reservoir management.

Introduction

Time-lapse seismic monitoring of fluid and pressure changes in carbonate reservoirs is gaining a lot of traction as most of the well-known giant carbonate fields start to decline in productivity (Adeyemi et al, 2014). Owing to the increasing demands to optimize recovery on these fields, specialized processing techniques (Blanco et al 2014; Pagglicia et al 2014) are required to get useful and interpretable 4D signal that will highlight depleted zones, flushed zones and by-passed oil for future infill-well drilling and optimal reservoir management. The challenge usually is that the 4D signal in most oil-bearing carbonate reservoirs is difficult to interprete and weak compared to 4D noise thresholds. In our case, the context is even more challenging. Although background repeatability is good (~12%NRMS), surface-related and inter-bed multiples are predominant and are difficult to distinguish from primaries. This is because the field has a flat structure, a repetitive geology, a shallow interval with strong reflectivity contrasts and a strongly-impedant seabed that is poorly imaged with about 60m of water depth.

3 narrow azimuth towed-streamer seismic surveys have been acquired over the field case: one baseline **(B)**, a pilot monitor **(PM)** after 14 years over two swaths and a full-field monitor **(FM),** a year after the pilot (figure 1). The base and monitor pairs have been co-processed using several 4D seismic processing routes, summarized in figure 1 below. In this paper, we summarise four main learning points that seem fundamental to achieving an interpretable 4D signal in similar challenging seismic and geological contexts. Our conclusions are heavily based on painstaking and iterative 4D QCs at every step of the seismic processing flow with the processing contractor and with strong interactions from asset geoscientists and reservoir engineers.



	Base (B) Survey	Pilot Monitor (PM) Survey	Full-Field Monitor (FM) Survey
Bin Size	3.125 x 25m	6.25 x 25m	3.125 x 25m
Orientation	152 deg	152 deg	152 deg
Fold	88	100	100
Source			
SP Interval	12.5m	12.5m	12.5m
Nb Source	1	1	2
Volume	2000 cu. in	2000 cu. in	1938 cu. in
Air Pressure	2000 psi	2000 psi	2000 psi
Nb Sub-Array	2	2	2
Depth	3m	3m	3m
Receivers			
Nb Cable	4	6 (4+2)	6 (4+2)
Cable Length	2200 m	2550 m	2500 m
Cable Interval	50 m	50 m	50 m
Group Interval	6.25 m	12.5 m	12.5 m
Depth	4 m	4 m	4 m
Near Offset	105 m	105 m	70 m

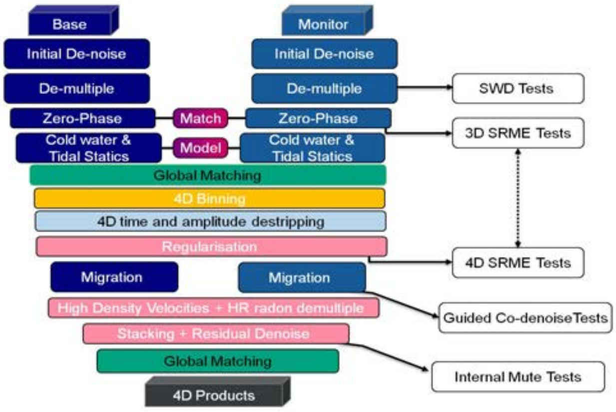


Figure 1 *4D seismic survey parameters and a simplified version of 4D seismic processing sequence*

Learning Point 1: In a 4D processing sequence in a difficult context, a simplified demultiple flow improves 4D metrics better than a complicated one.

Beyond the regular time and amplitude cross-equalization and imaging steps, the 4D demultiple flow was by far the most challenging processing step in our field case. The different water-layer conditions over the study area during each seismic campaign as well as the high reflectivities of the seabed and shallow layers leads to severe contamination of multiples that can be highly non-repeatable. Our experience shows that a complicated multiple model that attempts to predict all multiples and remove them using heavy adaptive methods may destroy 4D signal; introduce 4D noise and does not optimally attenuate non-repeated multiples. On the contrary, a relatively simpler targeted multiple model that aims to attenuate mainly non-repeated multiples with no adaptive process significantly improves all 4D metrics. We also note that repeated (inter-bed) multiples in base and monitor vintages cancel out in the 4D difference and any residual non-repeated multiples could be targeted at a later stage with standard Radon techniques.

Two tests from our 4D demultiple flows are highlighted below (figure 2):

- 1 model of demultiple (SWD) derived separately for base and monitor vintages and directly subtracted from data.
- 4 models of demultiple: Firstly, three models (2 SWD models + 1 model-based water demultiple (MWD) using reconstructed water bottom) were simultaneously and adaptively subtracted from

the data using a least square approach. Then, a 4D SRME was implemented by simultaneous adaptive subtraction of the 3D SRME models of the base and monitor vintages after regularisation (Khalil et al 2013). This was performed in offset inline domain.

Our tests show that multiples are better attenuated in the overburden using the simpler adaptive-free approach (refer to figure 2 below). Other tests indicate that the direct subtraction methodology improves 4D metrics better than the simultaneous adaptive subtraction approach.

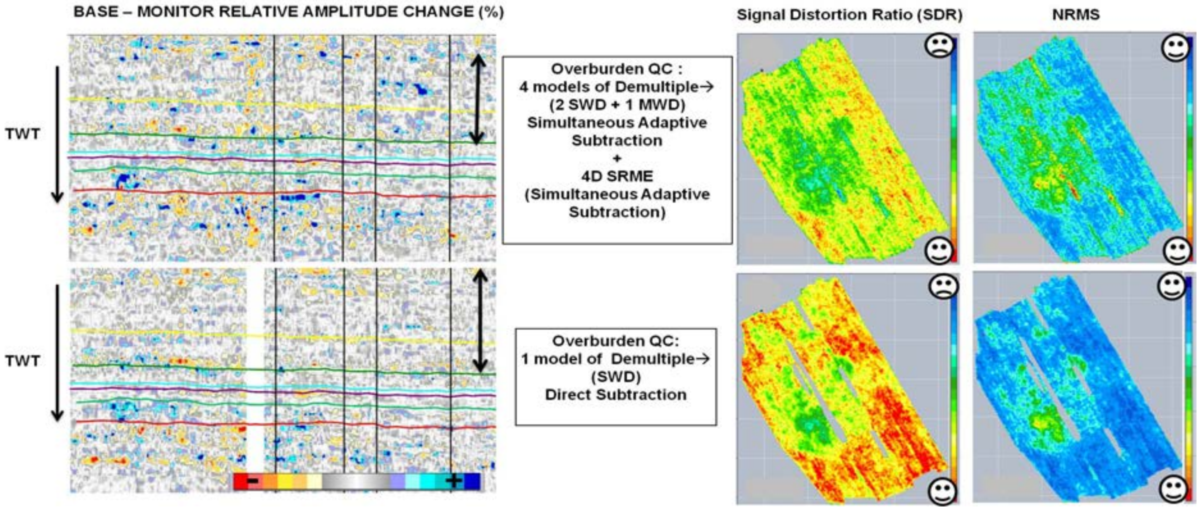


Figure 2 *Section top and bottom left showing relative amplitude changes between base and monitor. The overburden interval indicated by arrows are cleaner in bottom section with the simplified demultiple flow. SDR and NRMS maps bottom right show a step change improvement of 4D metrics in the overburden.*

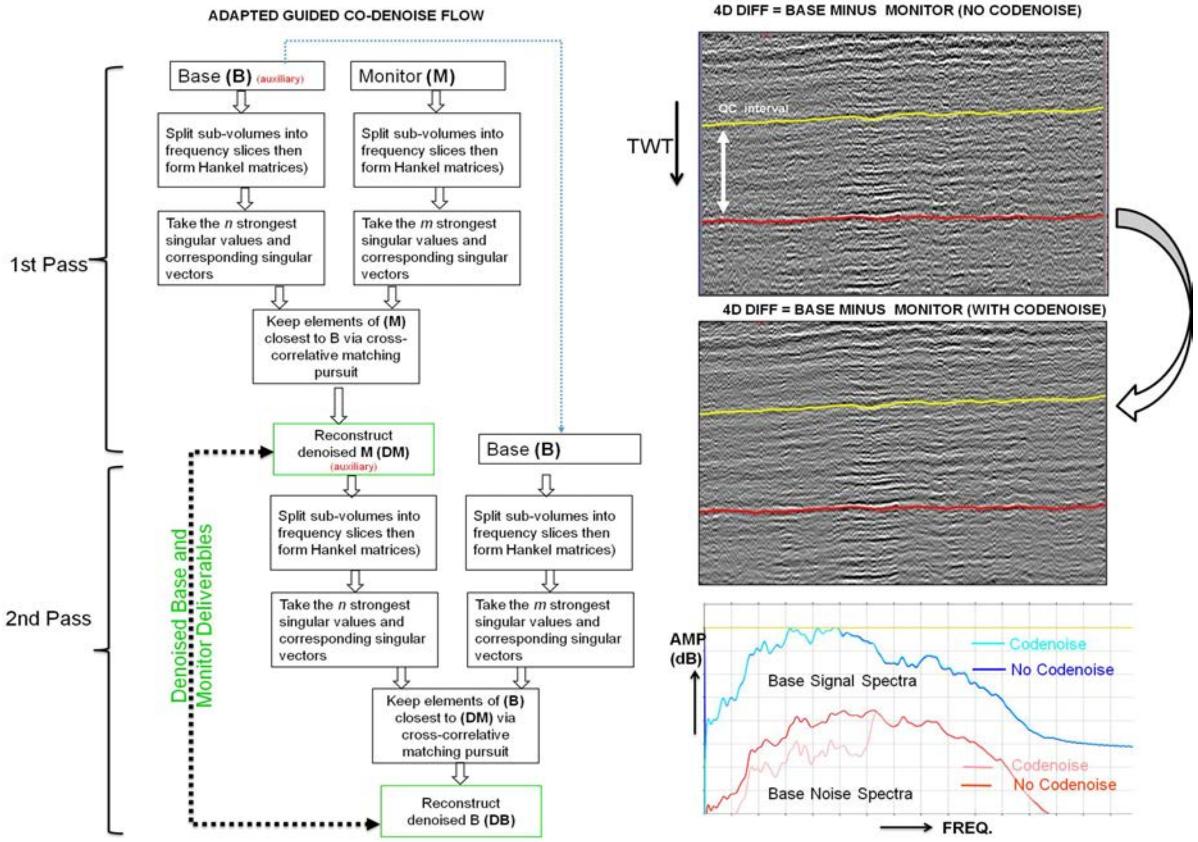


Figure 3 *Guided Co-denoise work flow (left) of base and monitor vintages in two passes (adapted from Roodaki et al 2014). 4D difference stack section before and after Co-denoise (top right). Base survey amplitude spectra (bottom right) show reduced noise spectra while still preserving signal.*

Learning Point 2: Guided Co-denoise of Base and Monitor vintages significantly improves 4D S/N while preserving timeshifts and amplitude changes.
This technique has been adapted from the well-published method of using P-wave hydrophone data to denoise noisy geophone (Z) data in multicomponent surveys. In Roodake et al, 2016's methodology, an auxiliary dataset is used to perform an adaptive denoising of a reference data based on cross-correlation matching pursuit. Random and erratic noises are attenuated with recovery of data in F-X domain. We have adapted this method using guided co-denoise approach which involves two passes of denoise: monitor denoised with base as auxiliary and base denoised with denoised-monitor as auxiliary (refer to figure 3, above). Our results show that this technique improves all 4D metrics: NRMS, SDR, Predictability while preserving 4D timeshifts and 4D amplitude changes. This technique has enhanced the interpretability of 4D signal over the field, while targeting mainly non-repeated noise. In difficult seismic contexts similar to ours, guided co-denoise should be tested and adapted on a case by case basis.

Learning Point 3: Optimization of mute design results in more coherent 4D signal after stack
The Near offset traces are noisy and highly multiple-contaminated even after extensive demultiple. However, they are also crucial for 4D seismic inversion to derive relative velocity/impedance changes. The challenge is usually to find the best compromise between attenuating residual noise and high frequency inter-bed multiples in the near offsets while still guaranteeing seismic inversion results fidelity. We have tested several mute scenarios and the impact on relative velocity changes after 4D inversion. As a QC, we have also performed well-synthetic modelling using Compressional and Shear sonic log data to assess the impact of these different scenarios at wells. Our results show that multiple reverberations highlighted by the 4D difference stack (figure 4) are attenuated by using an optimal mute design decided after seismic inversion tests and QCs at wells. An optimal mute design is crucial in seismic contexts where multiple energy is coherent with primary signal; and where due to survey restrictions, near offset traces are not well-populated which limits the efficiency of standard demultiple techniques.

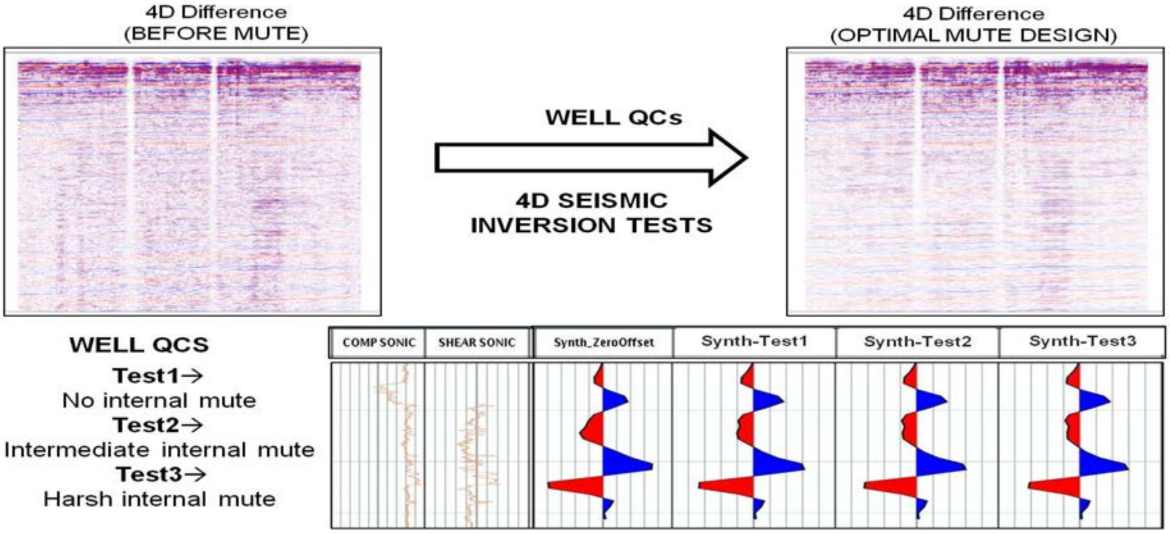


Figure 4 *Mute design optimization tests. Residual higher order multiples dominant on the near traces (top left) are attenuated with the optimal mute design, after QCs with seismic inversion results and with well synthetics (bottom).*

Learning Point 4: Interruptions in seismic acquisition operations have an impact on 4D projects, and thus should be avoided as much as possible.
In our field case, the base survey acquisition was stopped for a few days due to bad weather conditions and the last swaths were acquired after a few days as per pre-plot plan. At resumption, there were no overlapping sequences till the end of the base survey. Although, there were no such issues for the monitor survey (that "faithfully" repeated the baseline geometry), the imprint of interruptions during the baseline acquisition campaign is observable on computed 4D seismic

attributes (figure 5, below). This artefact was however not obvious on 3D seismic data. In such difficult seismic context as ours, acquisition constraints can severely impact 4D signal fidelity. This leads to the conclusion for all seismic monitoring campaigns in similar contexts, a rigorous approach is vital and every acquisition detail, constraints and limitations must be taken into account.

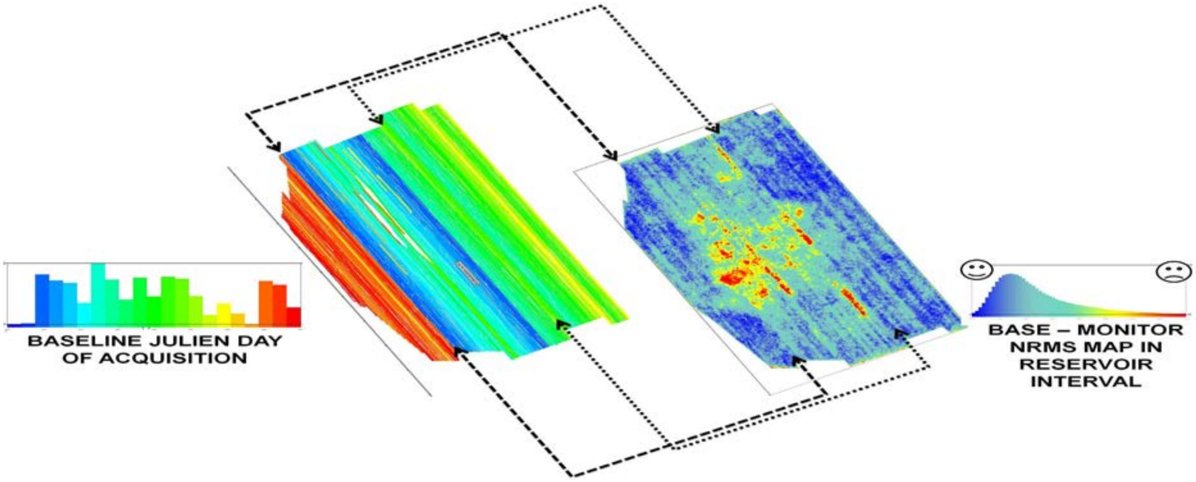


Figure 5 *Figure showing the link between seismic acquisition-related interruption and 4D attributes (NRMS). Acquisition-related artefacts like this are often difficult to remove with processing.*

Conclusions

Despite a challenging 4D seismic processing experience in our field case, we have put in a place, a processing methodology and an iterative QC strategy with strong multidisciplinary collaboration to deliver data with more interpretable 4D signal, with significantly lesser non-repeated multiples, and random/erratic noise. A simplified and constrained demultiple flow avoiding heavy adaptive methods; a guided co-denoise of base and monitor vintages, and a mute design optimisation assures 4D signal fidelity. We have also shown the sensitivity of acquisition operations and parameters to 4D seismic attributes, although this may not be totally obvious in 3D. It is our hope that future seismic monitoring campaigns in similar difficult settings as ours will benefit from some of our learning points. Finally, we note that a successful 4D seismic processing project must of necessity accommodate feedback from service providers, processing supervisors, asset geoscientists and reservoir engineers.

Acknowledgement

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References

Adeyemi, A., Brechet, E., Hubans C, Euriat, C.Pigeaud T., Emang, M. [2014] Initial Results of a Pilot 4D Seismic Monitor in a Difficult Shallow Offshore Carbonate Context - Dynamic Connectivity and Implications for Development. 76th EAGE Conference and Exhibition.

Blanco, B., Charron, P., Brechet, E., Pagliccia, B., Radigon, M. and Emang, M. [2014] SPE 172035 4D Seismic Processing Pilot, Offshore Qatar. ADIPEC 10–13 November 2014.

Khalil, A., Hoeber, H., Campbell, S., Ibram, M., Davies, D. [2012] An optimized workflow for coherent noise attenuation in time-lapse processing.75th EAGE Conference and Exhibition

Pagliccia, B., Cantine, F., Brechet, E., Brosile, E., Blanco, B., Charron, P., Emang, M. et al. [2014]. “From feasibility to Processing: a time-lapse seismic experiment on xxxx field – offshore Qatar”. SPE 17582 presented at the 2014 IPTC, Doha, Qatar.

Roodaki, A., Bouquard, G., Bouhdiche, O., Sternfels, R., Rollet, A., Lafram, A., [2016] SVD-based Hydrophone Driven Shear Noise Attenuation for Shallow Water OBS.75th EAGE Conference and Exhibition