4D OBN PROCESSING AND IMAGING OF A DEEPWATER FIELD. PART I: 4D MATCHED CO-PROCESSING

C. Ricardez[1], M. Vu[1], P. Ukerun[2], S. Iyiola[4], P. Nevill[3], R. Eslick[4]

[1] ION; [2] Bulwark; [3] Chevron Energy Technology company; [4] Chevron

Summary

Presented here are the results of the co-processing of the first-ever three Ocean Bottom Nodes (OBN) surveys in Africa over Agbami field in a water depth of more than 4800 feet. The objective of the co-processing was to ensure 4D repeatability in the second monitor survey (which had half as many source points as the baseline and first monitor surveys), enhance 4D signal, reduce 4D noise, and improve structural imaging in the 3D volume. These OBN datasets provide full azimuth, long offset, and low frequencies that facilitate specialized processing workflows and enable higher reliability in 4D seismic response. As exemplified in this case, even significant differences in OBN source can be overcome to produce good 4D results.

Full utilization of the data and careful application of each element in the workflow contributed to good 3D and 4D results. For 4D co-processing, wavelet equalization, deghosting, and multiple modeling with adaptive subtraction were employed, were all instrumental in maintaining 4D signal and reducing 4D noise. The multiple suppression techniques included 3D SRME and 3D MWD. This flow in conjunction with a rigorous 4D QC process were key in meeting the co-processing objectives.

4D OBN processing and imaging of a deepwater field. Part I: 4D matched co-processing

Introduction

Discovered in late 1998, the Agbami field was the second major deep water oil field discovered off the Niger delta. The field is located in OML 127 and OML 128 offshore Nigeria in water depth approximately 4800 feet (~1500 m). The baseline seismic survey covered 370 square miles (~950 km^2) of the Agbami Field and was acquired in 2009/2010. Monitor 1 and Monitor 2 surveys were acquired in 2012 and 2017 respectively. Two towed-streamer, narrow-azimuth (NAZ) seismic surveys had been conducted over the Agbami field in 1996 and 2004. While these datasets did not meet the requirements in illumination, bandwidth, Signal-to-Noise Ratio (SNR) and repeatability, they were included in processing as auxiliary datasets to help with multiple attenuation, one of the key steps in this effort. The processing of this data had to meet objectives of both detailed 3D reservoir characterization and 4D (time-lapse) reservoir surveillance to: 1) enhance the asset value of the field, 2) reduce risk/uncertainty of the drilling program and optimize reservoir management, 3) help mitigate risk of water encroachment and gas breakthrough, 4) identify bypassed reserves, and 5) extend the plateau production rate and increase ultimate recovery (Chou et al., 2010).

OBN datasets had already shown improvement over towed streamer datasets due to an increase in frequency bandwidth and SNR, which can be attributed to high fidelity recording, accurate wavefield separation enabled by multicomponent data, higher fold, full azimuthal illumination, longer offsets and an often quieter recording environment. However, further improvement in time-lapse products requires specialized processing. The key steps used to ensure our processing objectives can be grouped roughly as:

1. Wavelet equalization across all vintages
2. Timing corrections due to different positioning and water velocities
3. Multiple attenuation due to overlap between multiples and 4D objectives

Method and/or Theory

Wavelet equalization was ensured across all vintages by a shot-by-shot debubble filter design, PZ calibration/summation plus directional designature as preparation to vintage matching and receiver-by-receiver vintage matching after 4D binning. Near field hydrophone (NFH) data was provided for each vintage which was used to invert for the far field signature for every shot. Predictive deconvolution was used to derive a debubble filter for each shot.

Since OBN is full azimuth data, the downgoing wavefield above the first water-bottom (WB) multiple is essentially the source wavelet at every angle of propagation and therefore directly gives us the opportunity to do full 3D designature in TauPxPy domain. Figure 1 shows that vintage matching (phase and amplitude spectrum) after the completion of all individual vintage wavelet processing helps to further reduce 4D noise above the target.

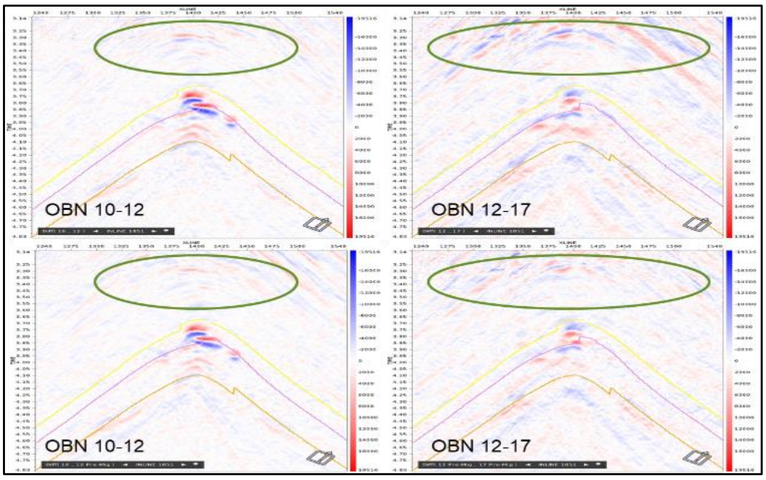

Fig 1. Kirchhoff down-going 4D difference full stack before (upper) and after (lower) vintage matching

There are 2 types of timing corrections applied: 1) deterministic, like subsample and tidal corrections; 2) DT based corrections, where DT is the difference between picked and theoretical direct arrival time. Source drag back is the difference between reported and actual source location in the inline direction. A range of shot drag values is scanned for each survey using near offset hydrophone data, where the correct value minimizes the standard deviation for computed DT (picked – theoretical direct arrival time) (Figure 4). DT analysis is also used for node position, water velocity correction and node statics, which are computed as a joint inversion. Figures 2 and 3 show the combined effect of all these individual timing corrections in both DT QC itself and 4D difference.

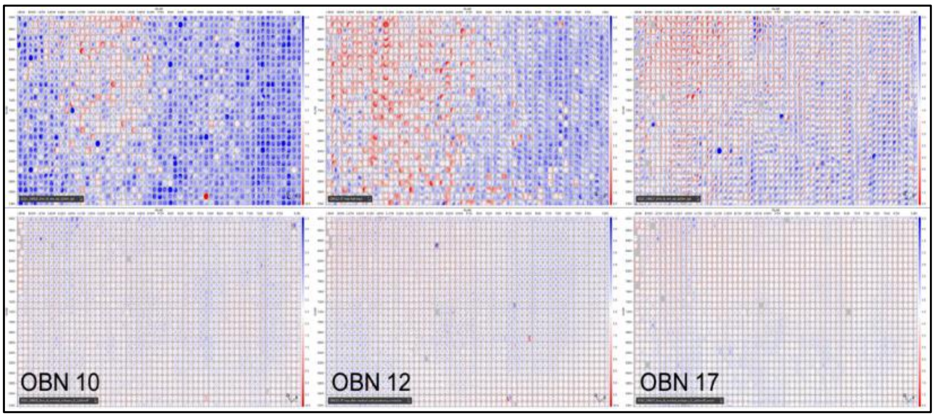

Fig 2. DT map QC before (upper) and after (lower) all shot/channel positioning and timing corrections for OBN10 (left), OBN12 (center) and OBN17 (right)

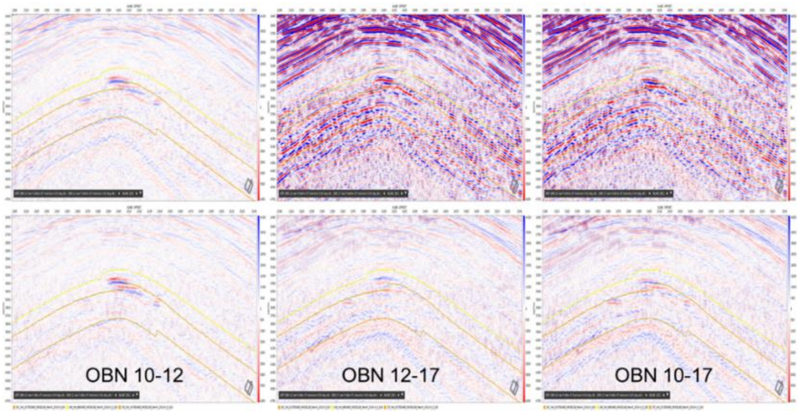

Fig 3. 4D difference (left: OBN10-12; center: OBN12-17 and right: OBN10-17) of down-going migration full stack before (upper) and after (lower) all shot/channel positioning and timing corrections

Source-side multiple attenuation was the most important pre-processing step for this particular project because the 1st bounce of water bottom multiple (the strongest one) is roughly at the same depth as the reservoir level after migration. 3D SRME and 3D MWD were both used to target free surface multiples. Both methods have their advantages and disadvantages. MWD provides more bandwidth because it’s not squaring the wavelet by convolving data with data, but data with the Water Bottom’s Green’s function. However, it requires accurate bathymetry and can only predict WB related multiples. SRME is fully data-driven, its bandwidth is reduced due to wavelet squaring from data convolution, however it predicts all surface related multiples, including WB. SRME can only predict multiples using data datumed at the free surface. With sparse node acquisition, accurate redatuming of receivers is extremely challenging, if not impossible. With streamer data, the SRME multiple model can be kinematically accurate because redatuming of towed receivers is trivial. SRME and MWD multiple models were predicted for both down-going and up-going data. Since WB multiples are predicted by both SRME and MWD, we used joint adaptive subtraction to combine the models, where the inversion optimizes both filters simultaneously.

For up-going data, besides MWD and SRME models, an up-down deconvolution multiple model was generated and utilized as well. First, the up-down deconvolution multiple model was generated following a straight PZ sum process, also referred as separation above the seabed. Then, this model was used along with the MWD and SRME models, in a joint three-model adaptive subtraction. The subtraction was done on upgoing data generated by curvelet based PZ summation, which is essentially locally optimized for residual denoise, multiple attenuation, residual PZ matching and obliquity correction. Joint subtraction showed better preservation of primary events and fewer artifacts compared to cascaded subtraction (Figure 4).

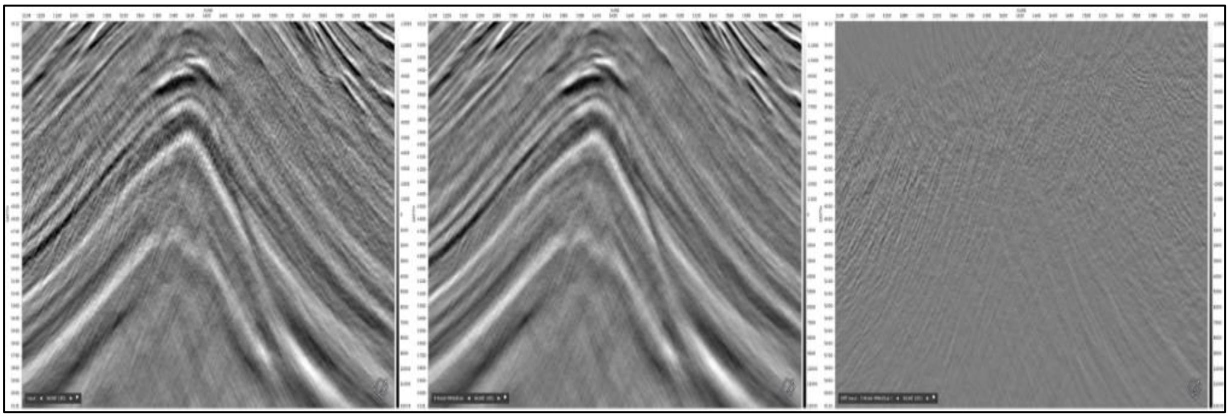

Fig 4. OBN12 Kirchhoff up-going image before (left), after (centre) and difference (right) SRME/MWD/up-down deconvolution model joint subtraction for OBN10 survey

In the image domain, residual denoise and 4D statics were applied. Comparing curvelet domain spectra between different vintages enables us to identify residual 4D noise in both pre-stack and post-stack domains. Figure 5 shows 4D difference QC after the application of post-stack dip-based denoise. Residual statics were also applied as pre-stack (trim statics) and post-stack (residual statics) processes.

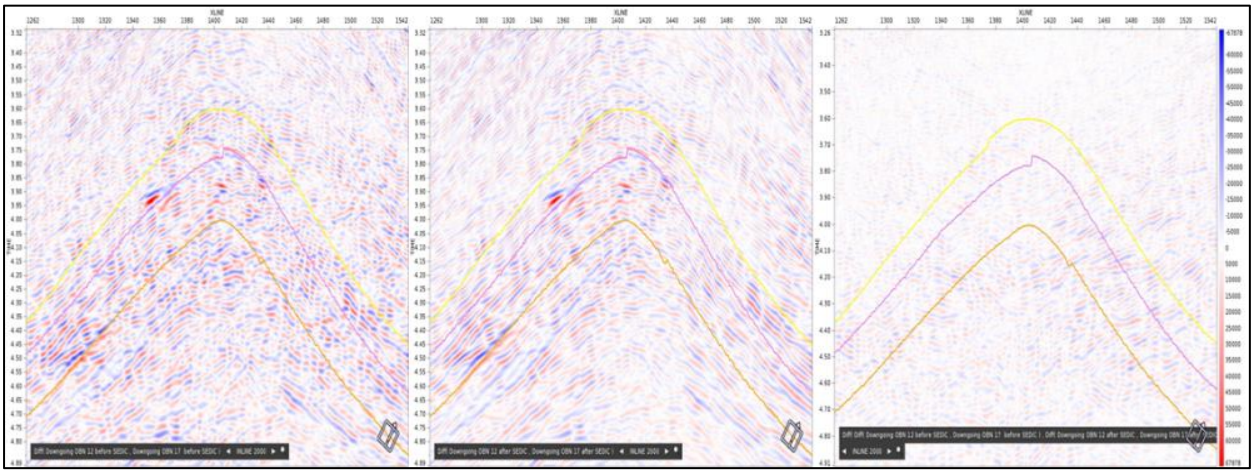

Fig 5. 4D difference down-going full stack OBN12-17 before (left), after (center) and difference (right) after dip-based denoise

Conclusions

Since the acquisition of the original base survey in the Agbami field, it was confirmed that OBN data's rich azimuthal and bandwidth content as well as its superior signal-to-noise ratio would be better suited for objectives beyond seismic exploration: namely field development and reservoir surveillance. Ten years have elapsed since the acquisition of the original vintage data, and processing technology has evolved significantly in the meantime. After careful 3D and 4D quality control, we have been able to confirm that the latest processing workflows allow us to unlock the full potential of these OBN datasets. Through all these processes, we are able to improve 4D attributes such as 4D difference and NRMS, compared to raw field data and legacy processing.

Acknowledgements

We would like to thank Chevron Nigeria and their partners: NNPC, Equinor, FAMFA Oil and Petrobras, for their support and permission to publish this paper. Also, we would like to thank Bulwark-ION for permission to show this work.

References

Cantillo J., J. Boelle, A. Lafram, and D. Lecerf (2010) Ocean bottom nodes (OBN) repeatability and 4D: 80th Annual International Meeting, SEG, Expanded Abstracts.

Chang J., M. Vu, I. Berranger, C. Osolo, S. Iyiola and Nanqun He (2020) 4D OBN processing and imaging of a deepwater field. Part II: FWI high resolution TTI model building

Chou T. G., D. Hicks, L. Sydora, S. Iyiola, N. Nworah, and I. Arowolo (2010) OBN (Ocean Bottom Nodes) Acquisition for reservoir management and surveillance at Agbami Field, Nigeria: 80th Annual International Meeting, SEG, Expanded Abstracts, 3756–3758.

Detomo, R., E. Quadt, C. Pirmez, R. Mbah & S. Olotu (2012) Ocean Bottom Node Seismic: Learnings from Bonga, Deepwater Offshore Nigeria, 82nd Annual International Meeting, SEG, Expanded Abstracts.

Dragoset, B., E. Verschuur, I. Moore, and R. Bisley (2010) A perspective on 3D surface-related multiple elimination: Geophysics, 75, no. 5

Jin, H and P. Wang, 2012, Model-based water-layer Demultiple (MWD) for shallow water: from streamer to OBS: 82nd Annual International Meeting, SEG, Expanded Abstracts.