From Multicomponent Broadband Seismic Acquisition, Imaging to 4D Processing - Potential Improvement of Seismic Interpreta

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SUMMARY

A case study was carried out over the Oseberg East Field where 2015 acquired multi-component broadband seismic data is being used to demonstrate potential improvement of structural interpretation. In particular, we have focused on impact of adopted 3D model based SRME for multiple attenuation and velocity model building including FWI, in broadband processing. Additionally, we present initial results from 4D repeatability strategies (conventional vs broadband acquisition). We aim to show that 3D processing of low-frequency rich broadband data has the potential to improve 4D processing sequences even with conventional vintage surveys.

Introduction

In this paper, we present a case study of the Oseberg East (OSØ) field with an objective to improve the seismic imaging quality that is directly linked to business value creation and where we have utilized recently acquired multicomponent streamer data. The OSØ field is located in block 30/6 in the North Sea, approximately 120 km offshore Bergen, Norway. Conventional single hydrophone streamer seismic has been acquired in 1998, 2003 and 2006. The processing results of these surveys have been used for production monitoring and further field development planning. In 2015, a dual-sensor streamer seismic survey was acquired with the main objective of improving the structural imaging and reservoir interpretation, enabled by broadband seismic solutions. A secondary objective was to reprocess the 1998 conventional data vs. the 2015 broadband data for 4D interpretation.

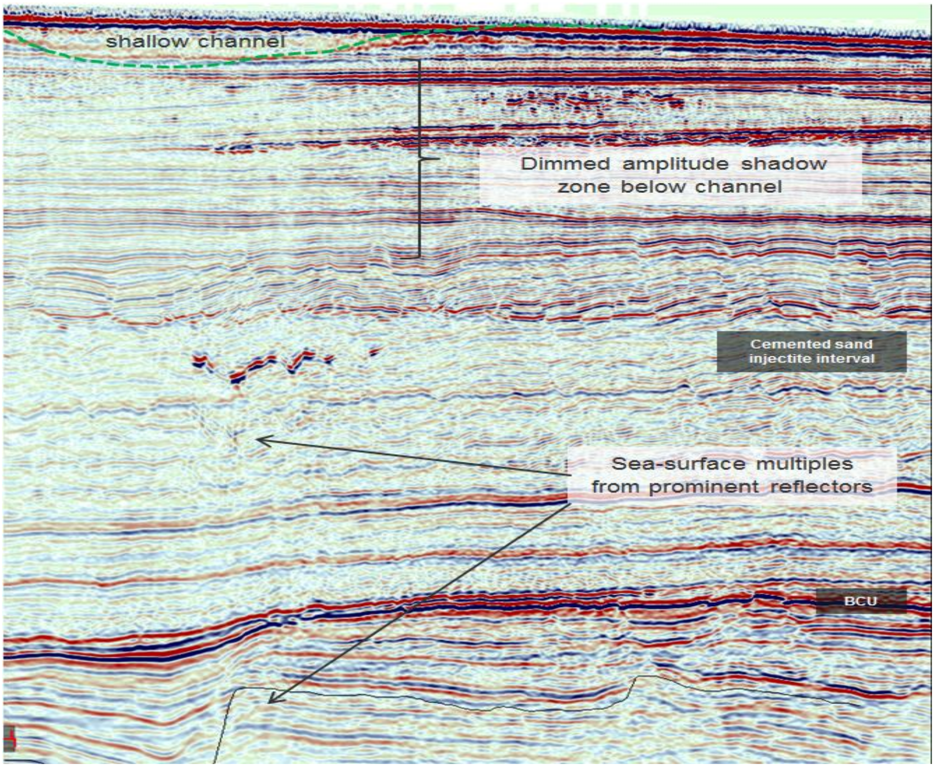

Figure 1 *Seismic data quality challenges for Oseberg East field.*

The field presents several challenges with respect to data quality. A shallow channel exists in the over-burden above target zone, which causes significant amplitude dimming, as seen in *Figure 1*. The area is characterized by strong overburden reflectivity, including the seabed, generating many orders of short period multiples both in shallow and in the deeper reservoir area. In addition, the reservoir interval is heavily faulted. The associated seismic data processing challenges consist of maximizing the recoverable resolution at reservoir depth, , improving the fault imaging with better low frequency content and more a accurate velocity model. In this paper, we describe how different processing sequences e.g. multiple attenuation, velocity model building of the 2015 acquired multicomponent streamer data potentially improves structural interpretation. In addition, we demonstrate preliminary results on 4D repeatability strategies (conventional vs broadband).

Improved multiple attenuation via broadband-enhanced Model based 3D SRME

A state-of-the-art processing sequence was established with the 2015 dual-sensor streamer acquisition, providing inherently de-ghosted data (Oukili 2015). A Complete Wave field Imaging (CWI) methodology was applied for velocity estimation and for comprehensive 3D de-multiple. This is fully applicable to the 2015 survey that contains sufficient long offsets, more lower frequency signal and separated up- and down-going wavefields. The de-multiple step is achieved using a combination of two methods: 3D wavefield modelling and 3D seabed convolutional SRME (Barnes 2014). Both methods are useable in shallow water enviroments by reconstructing the shallow overburden reflectivity with Separated Wave field Imaging (SWIM) (Oukili 2015) and Seabed bathymetry information respectively. The two are then combined to provide optimal attenuation of short period multiples . Longer period multiples are subsequently attenuated by running muted 3D convolutional SRME, thus enabling robust multiple attenuation at all depths.

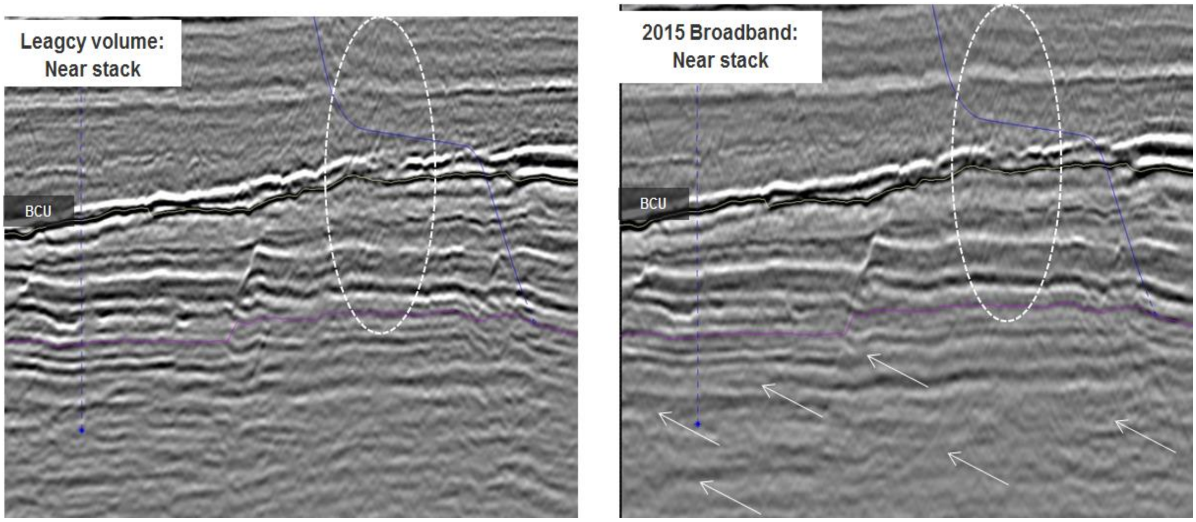

Figure 2 *Effectiveness of 3D model-based SRME de-multiple for OSØ Broadband data.*

As shown by arrows in *Figure 2*, the latest seismic from the PSTM processing route has far less remaining sea-surface related multiples compared to legacy data, which was re-processed in 2014. These multiples are mainly originated from the base cretaceous unit (BCU) and cemented sand injectites in the interval above. We observe that the de-multiple sequence applied "un-masks" the true amplitude response from the background multiple contamination (shown by highlighted circle in *Figure 2*) . Hence this leads to better event continuity and interpretability. Still there is evidence of remaining multiples even after several passes of de-multiple. But as a more aggressive de-multiple has the risk of decimating primary reflection amplitude, one needs to find an optimal trade-off.

Uplift in Velocity Model building via FWI and Corresponding Depth Imaging

At the OSØ field, the very shallow overburden is affected by a low velocity channel and thin layers of varying velocities. In order to overcome the amplitude dimming in and below the shallow channel, Full Waveform Inversion, FWI (Korsmo 2015) has been used. Refracted events (mid to far offsets) are isolated and used in this methodology. After convergence, the FWI derived velocity model was merged with the wavelet shift tomography model and subsequently led towards an optimal velocity model. The centre column of *Figure 3* shows shallow depth slices with the initial velocity model and updated FWI models. The low amplitude in the shallow channel is very well captured in the FWI case. The final depth imaging has been produced using a Kirchhoff pre-stack depth migration (PSDM) algorithm after additional source side de-ghosting of the input data. A Q-model has also been used to compensate for absorption and dispersion effects during the application of the migration operator. In addition, we have determined the anisotropy parameters i.e. Thomsen's delta and epsilon over the entire interval of interest. The lower half of *Figure 3* shows a full stack seismic data comparison from the 2014 re-processed data and the latest depth migrated data from processing stretched back to the time domain. As it is highlighted in the figure, the impression of the major bounding faults are clearer in latest PSDM stacked section. Also of note is the improvement in the continuity of reflector along the area of interest. This is potentially an important uplift; not only for better understanding of structural setting, but also for reservoir characterization and subsequent geophysical analysis. A velocity model based on the low frequency-rich multicomponent streamer data is an enabler in this case.

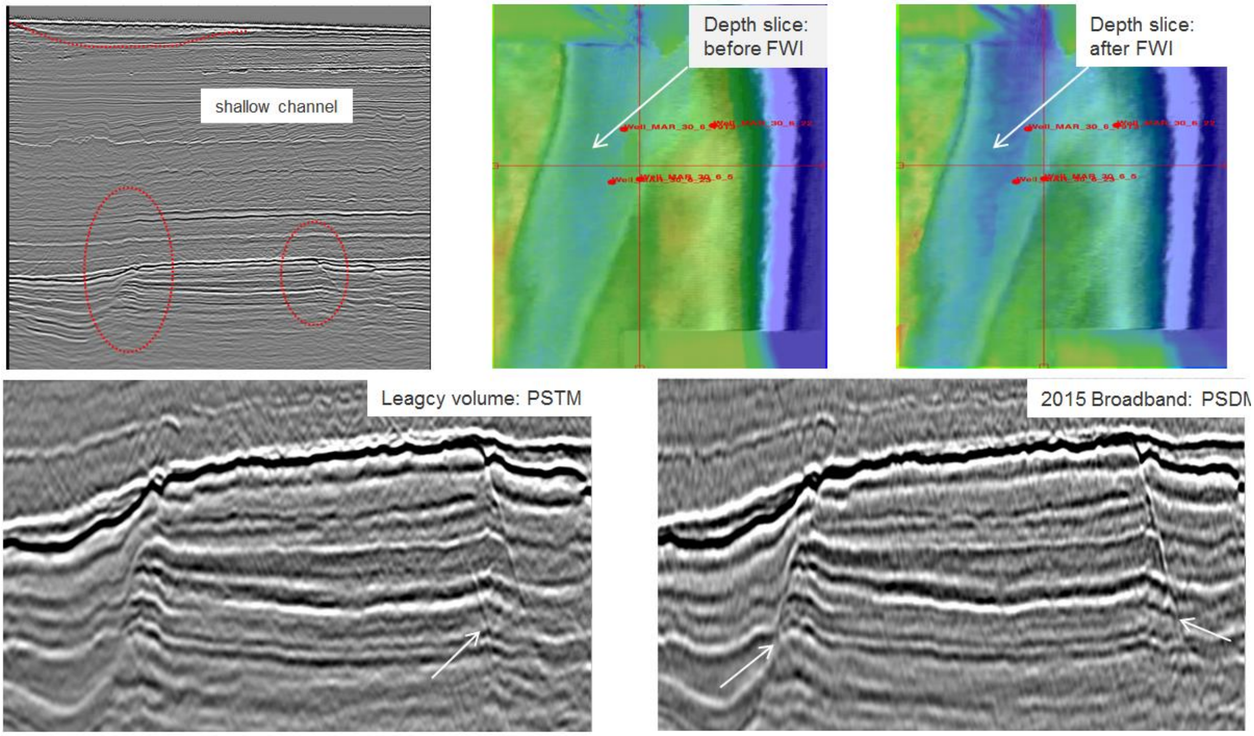

Figure 3 *Improved velocity model in shallow over-burden of OSØ via FWI and tomography.*

Application of the 3D broadband processing route for 4D reservoir monitoring

A 4D processing of 2015 data is currently being performed against the 1998 vintage. Given the availability of the de-multiple attributes (high-resolution reflectivity cube), the same 3D broadband flow can be applied to the conventional vintage datasets.

Initially the conventional 1998 data must be de-ghosted in order to simulate the up-going wave field of the 2015 data. This is achieved using a deterministic processing-based 2D de-ghosting solution. Whilst the similarity is greatly increased in most of the data bandwidth, the conventional data still shows a poor signal-to-noise ratio at low frequencies, as expected. The processing is finally carried out at 4 ms, to a maximum frequency of 125 Hz, which means that the maximum recoverable bandwidth of the conventional data is well constrained between the ghost frequency notches, on receiver and source side (7 m and 5 m deep resp.). The dual-sensor streamer data shows a greater signal-to-noise ratio than the 7 m towed single hydrophone streamer data. This is illustrated in the upper part of *Figure 4*. At very low frequencies, the 2015 dataset will be downgraded towards the conventional data bandwidth. It is clear that a only repeated broadband 4D seismic acquisition survey can possibly yield good signal-to-noise ratio across the full broadband bandwidth. Nevertheless the overall bandwidth is still greater than the one obtained using two conventional datasets without any de-ghosting. NRMS measurements are not used to assess the quality of this process since its value is relative to the effective data bandwidth which has been greatly modified.

Multiples and water layer statics are typical examples of non-repeated acquisition effects that can contaminate the 4D difference in both the shallow and deep sections. The de-multiple flow that was established during the 3D broadband processing addresses several of the residuals, in particular in the shallow where there is no expected 4D signal. We use a cross-correlation implementation of the residual 4D corrections that address variations from sail line to sail line within each survey, which are due to sea state effects and/or water velocity changes. Prior to residual sail line dependant corrections, the 4D global spectral amplitude matching is applied to further equalize the two datasets in a statistical manner. The sail line statics are then derived using a shallow overburden section which is

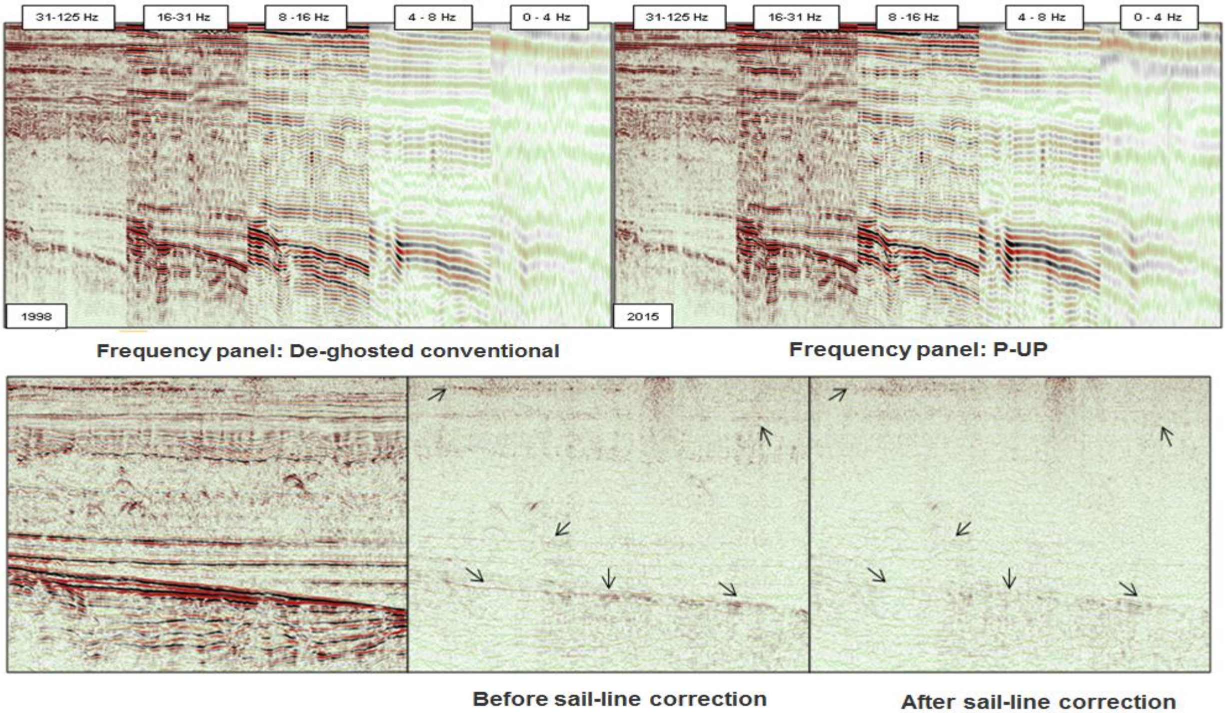

Figure 4 *4D processing: Frequency equalisation of vintages & sail line corrections.*

expected to be free of 4D signal. With much less multiples in the analysis window, the statics compensate for incorrectly aligned primary signals at all depths, see lower part of *Figure 4*. As a result, the corrections considerably reduce the primary leakage in the 4D difference at all depths inside and outside the computation window and potentially making the expected 4D signal more distinctive. 4D processing is still on-going, but initial 4D repeatability results looking promising, that considering the inherent challenges in relation to repeating legacy streamer survey with 2015 multicomponent acquisition.

Conclusions

As processing of 2015 acquired seismic data approaches its closure, we have started to observe the overall uplift in seismic data quality coming from the multi-component broadband streamer data. We believe that this improved insight of seismic imaging would be important for further production and development of the field.

Acknowledgement

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