Elastic Inversion of Deep-Water Field OBN Down-Going Wave Seismic Data

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ABSTRACT

In this paper, we discuss the elastic inversion of Ocean Bottom Nodes (OBN) down-going waves seismic data in Egina Field, which is in water depth of 1500 m offshore, Niger Delta. The OBN seismic data was acquired to address significant energy loss at reservoir zone observed in legacy streamer data and to serve as 4D baseline. Although the energy absorption in the reservoir zone was significantly reduced in the OBN data through processing and imaging, it remained a challenge in the 3D inversion process. We detail our AVA-consistent post stack amplitude correction implemented on the dataset prior to inversion. A multi-well inversion-based wavelet estimation process was used to derive the appropriate wavelet for each sub-stack using 6 vertical wells. Furthermore, the velocity model derived from the full waveform inversion served as input for the low frequency models (Ip and Vp/Vs). Very good correlations were obtained between the seismic velocity and impedances (Ip and Is) as well as Vp/Vs, though higher dispersions were observed in the shallow section. The final low frequency models were derived from the kriging of filtered well-derived Ip and Vp/Vs logs while using the derived Ip and Vp/Vs cubes from seismic velocities as external drifts. The elastic inversion, which is based on conjugate gradient algorithm, yielded robust and highly consistent elastic properties due to the high-quality low frequency content and high signal-noise ratio. We also computed probability of success for a more quantitative estimate of the degree of reliability of the inverted and derived properties compared to actual well log data.

Keywords:

INTRODUCTION AND GENERAL GEOLOGY

Egina Field, which was discovered in 2003 in water depths of about 1500 m, is located ~150 km offshore Nigeria in Oil Mining Lease (OML) 130. The Field is in the internal part of the compressional tectonic zone, which is dominated by toe-thrusts in a zone known as the Central Plateau (Figure 1). The reservoir consists of turbiditic channel complexes of Miocene age with a NE-SW trending dual-culmination anticline.

High seismic energy loss in the reservoir zone (due to shallow gas effects and mud volcanoes) necessitated the acquisition of Ocean Bottom Nodes (OBN) survey in order to improve the imaging and subsequently the reservoir characterization (Figure 2). This first OBN survey on the field will be the baseline for subsequent monitor OBN surveys. This seismic acquisition technique is not only preferred for reservoir monitoring because of its high repeatability in highly obstructed zone, but it is also the technique of choice for reservoir characterization. In addition,it is highly suitable for earth model building using Full Waveform Inversion (FWI)due to its characteristics long offset, full azimuth data and high-quality low frequency content (Chakraborty, 2017). Chen et al. (2020) provide further details on the FWI and imaging procedure adopted for Egina Field.

Post Stack Processing Amplitude Correction Prior to Elastic Inversion

Narrow azimuth streamer seismic data on Egina Field suffers from significant energy absorption due to shallow gas pockets and mud volcanoes. Consequently, 3D seismic inversion was not sufficiently reliable for reservoir characterization. A typical section illustrating the absorption effect is shown in Figure (left image). While the absorption in the reservoir zone was significantly reduced in the

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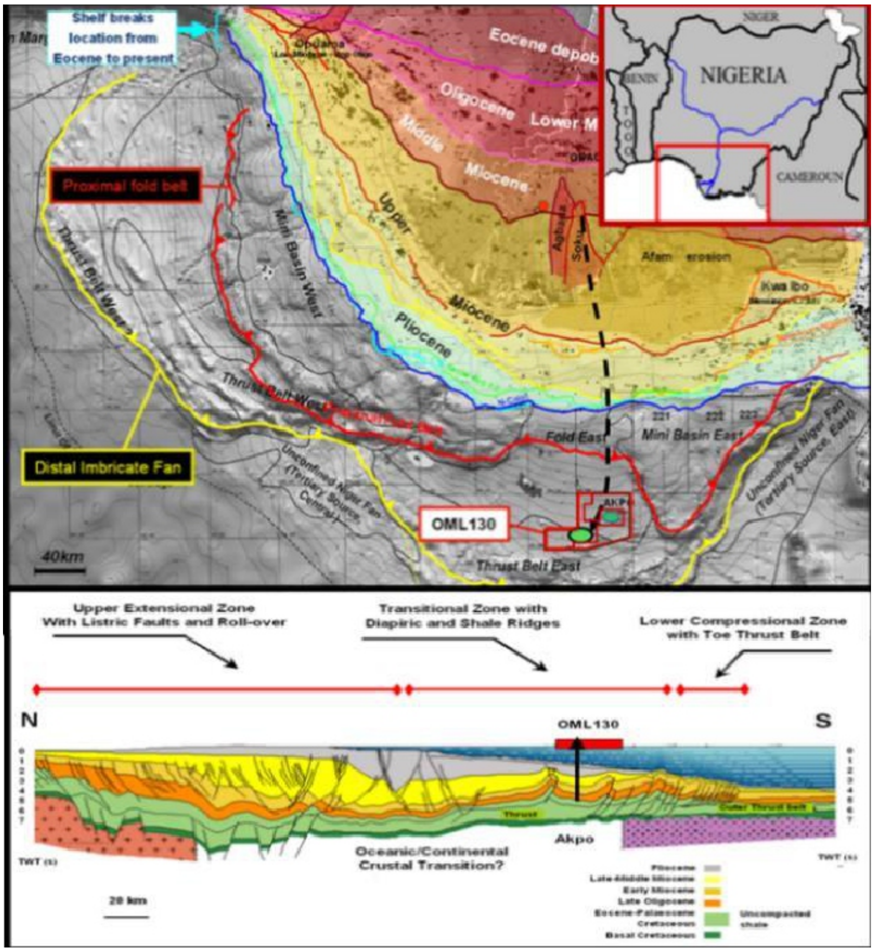

Figure 1: Location of Egina Field, Deep Offshore, Niger Delta.

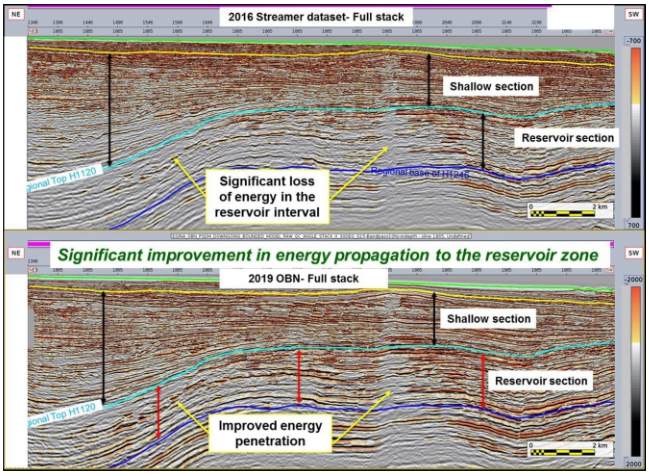

Figure 2: Comparison between Streamer (Upper) and OBN (lower) data.

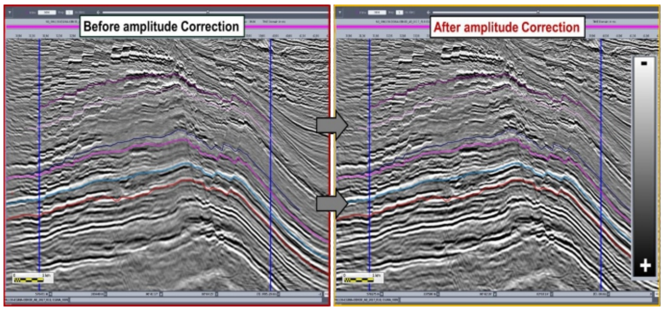

Figure 3: Post Processing AVO-consistent amplitude correction. (Left) Near angle stack section before correction and (right) after correction. The same correction procedure was repeated for all angle stacks.

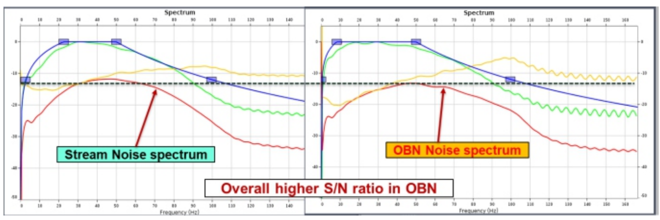

Figure 4: Spectral Comparison between Streamer and OBN data. Note the lower noise content in the OBN data.

OBN data through processing and imaging, it remained a challenge in the 3D inversion process. A post stack AVO-consistent amplitude normalization (correction) was applied prior to running the model-based inversion process. The correction procedure is briefly described below:

- o Pre-correction AVO/AVA response check
- o Angle-stack separation into frequency bands- based on energy decay profile
- o Compute amplitude ratio between overburden and reservoir interval of interest
- o Select a 'normal' response zone where ratio is close to 1
- o Compute average RMS in the reservoir and in the selected normal zone
- o Correction factor is obtained by the ratio of the rms average in the zone and the reservoir
- o Apply an appropriate smoothening operator to the correction map
- o Apply correction map, re-combine frequency bands and re-check for AVO/AVA consistency post correction

The above sequence is performed on each frequency band and all angle stacks.

OBN Wavelet, Low Frequency Model and Elastic Inversion

Egina Field OBN seismic data is generally rich in high quality low frequency content compared to the legacy streamer data on the field. The high-quality low frequency content is due mainly to the low ambient noise environment at the seafloor, high sensor sensitivity and source side de-ghosting, in addition to the natural receiver de-ghosting. Data analysis showed that with a

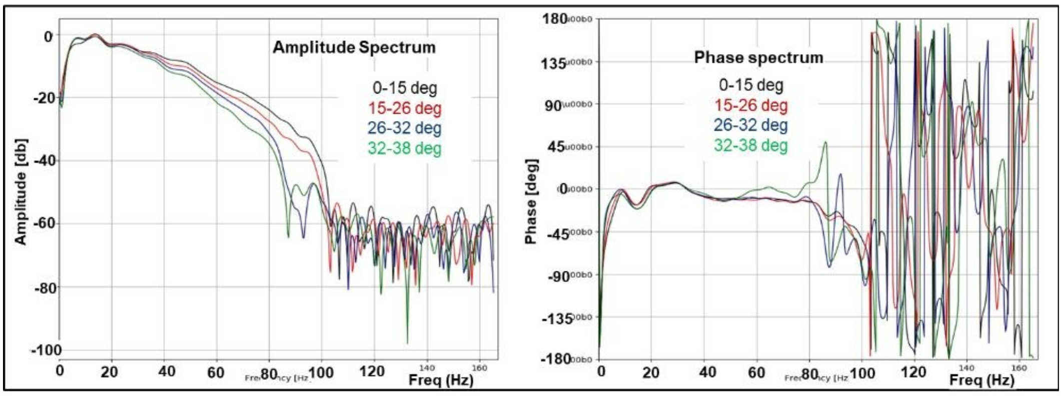

Figure 5: Amplitude and phase spectra of extracted multi-well wavelets for the OBN seismic angle stacks

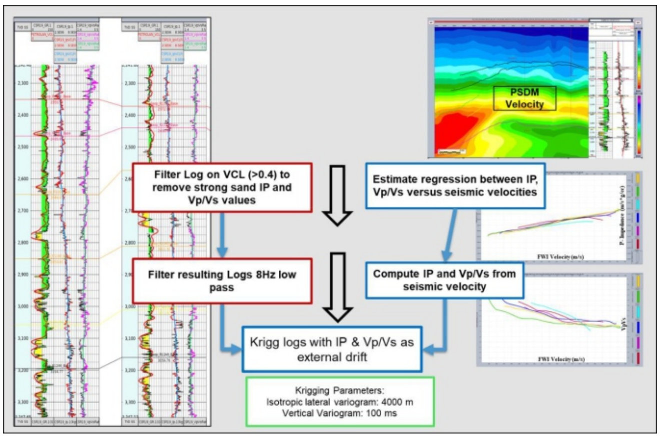

Figure 6: Low Frequency Model (LFM) building procedure.

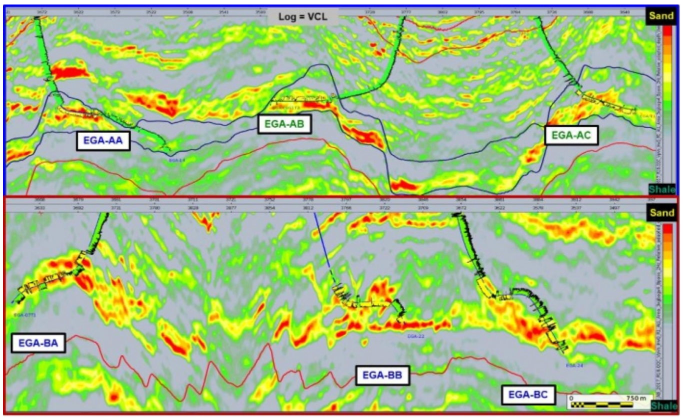

Figure 7: Calibration of Inversion result (Vp/Vs) at blind development wells.

SEISMIC CHARACTERIZATION BLIND TEST SUCCESS RATE		
WELL NAME	OBN Seismic Characterization Success Rate	Vintage Seismic Characterization Success Rate
EGINA-AG	83%	70%
EGINA-BB	80%	44%
EGINA-BC	74%	52%

Figure 8: Probability of successful sand prediction for inverted OBN and streamer (Legacy) data.

conservative parameterization of amplitude Q-compensation, a good quality high frequency content without significant noise increase (present in streamer data) was achieved. Additionally, the OBN data has low noise level (i.e. high signal/noise ratio) when compared to the legacy streamer data (Figure 4).
A multi-well inversion-based wavelet estimation process was used to derive the appropriate wavelet for each sub-stack using 6 vertical wells.

The velocity model derived from the full waveform inversion served as input for the low frequency models (Ip & Vp/Vs). While very good correlations (>90%) were obtained between the velocity and impedances (Ip & Is), correlation with Vp/Vs however, shows higher dispersion especially in the shallow section (low values of Vp/Vs). This observed weakness was accounted for in the inversion scheme parameterization. The final low frequency model was derived from the kriging of filtered well-derived Ip and Vp/Vs logs while using velocity-derived Ip and Vp/Vs cubes as external drifts. The procedure is illustrated in the figure below.

Our model based elastic inversion scheme, based on conjugate gradient algorithm, computes stepwise updates to the solution to approach the mean of the posterior PDF yielding Ip and Vp/Vs.

Calibration of Inversion Results and Probability of Successful Prediction
The elastic inversion results (acoustic impedance and Vp/Vs) were combined for further lithology classification studies. Overall, the inversion process achieved an excellent level of correlation not only at the input well locations but also at blind development wells. Moving beyond a qualitative description of correlation between well results and inverted properties, a more quantitative estimate of the correlation was implemented via the computation of probability of success. This computation (on sample basis) compares well log Vclay with OBN predicted Pseudo Vclay. So far, it has been implemented for some of the development wells in this on-going project with probability of success going as high as 83% (Figure 8). Thus, showing a significant improvement in reservoir characterization reliability over the prior narrow azimuth streamer data.

CONCLUSIONS

PSDM processing and application of least square full-waveform inversion on Egina Field deep-water OBN seismic data yielded a robust velocity field that addressed (to a large extent) issues encountered in prior narrow azimuth streamer data acquired on the field. Observed improvements include; better energy penetration at the reservoir level, a robust velocity field, high-quality low frequency content and improved signal to noise ratio. A post stack AVO/AVA-consistent amplitude normalization (correction) was applied prior to running the model-based impedance inversion process. The low frequency model was derived from the kriging of filtered well-derived Ip and Vp/Vs logs while using velocity-derived Ip and Vp/Vs cubes as external drifts.

A model-based elastic inversion of the down-going wavefield yielded a robust and highly consistent elastic properties due, in large part, to the high-quality low frequency content. The probabilities of success of sand prediction at blind wells revealed greater reliability of inverted products from the OBN seismic data relative to those from the legacy streamer seismic data.

REFERENCES CITED

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Chen, S., Usman-Lecky, N., Okougbo, T., Saragoussi, E., Mascomere, J.P., Pou Palomé, S., Tyagi, T. and Olagundoye, O. (2020) Ocean Bottom Node and Full Waveform Inversion for high-resolution earth model, deep-offshore Nigeria. SEG International Exposition and 87th Annual Meeting Extended Abstract.

General comments: Like it has been done for OBN, the various abbreviations/terms (e.g. AVA, AVO, Ip, PSDM) need to be defined at first introduction at various sections in the paper. That way, a non-traditional seismic processing specialist can benefit from reading the paper.