Enhancing Seismic Data Interpretability and Opportunity Capture using Integrative Spectral Enhancement and Noise Cancellation Tools

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ABSTRACT

Despite intensive mitigating efforts to reduce noise during acquisition and processing, removing noise from seismic data is an important step during data interpretation for accurate subsurface characterization. Consequently, various algorithms have been developed and are available in standard industry software for seismic data conditioning prior to data interpretation. This study highlights the impact of integration of spectral enhancement and noise cancellation workflows, which are parts of a vendor software, on data interpretability and opportunity capture. Our target opportunity is a deep-seated prospect within an NNPC/MPN Joint Venture (JV) field offshore Niger Delta, which was poorly imaged due to weak amplitudes in deep sections and noisy seismic data. The noise expression workflow was applied to reduce impact of coherent and random noise, whereas spectral enhancement algorithm was applied to increase contribution of frequencies with a weaker signal, thus improving resolution and frequency content of the seismic data. Overall, seismic imaging and reflection continuity improved, whereas weak amplitudes in deep sections were also enhanced. The integrative application of spectral enhancement and noise expression workflows gave higher confidence in horizon interpretation, more reliable attribute analysis, clearer visibility of subtle geologic features, and overall improved characterization of the target opportunity.

Keywords: Seismic Interpretation, Noise Cancellation, Spectral Enhancement, Opportunity Generation.

INTRODUCTION

Over the years, seismic imaging has emerged as a fundamental method for hydrocarbon exploration, where seismic data is acquired, processed, and subsequently interpreted to understand subsurface structural and stratigraphic features that could be potential targets for petroleum accumulation (Yilmaz, 2001). However, seismic data are inherently contaminated with noise. This noise occurs at all stages of seismic imaging, starting from data acquisition through to processing and final stage of seismic interpretation (Yilmaz, 2001; Ernst et al., 2002). Thus, a fundamental focus in seismic acquisition and data processing is to effectively remove noise while preserving primary reflections which constitute the medium of the information about the subsurface structure. The presence of noise in seismic data affects the signal-to-noise ratio and obscures details thus degrading final data quality, and complicates identification of useful information (Schimmel and Paulssen, 1997). Data can contain both coherent and random noise, including wind or swell noise, mud roll, ambient noise, and seismic interference (Yu et al., 2016; Ernst et al., 2002). Each of these must be uniquely addressed and can require applying different and combination of methods during acquisition and processing (Ernst et al., 2002; Djarfour et al., 2014; Schimmel and Paulssen, 1997).

Seismic data are also affected by attenuation, which is an intrinsic property of rocks causing dissipation of energy with depth (Dasgupta and Clark, 1998). As seismic waves propagate through the subsurface during acquisition, their amplitudes are reduced due to loss of energy (Ziolkowski and Fokkema, 1986; Ernst et al., 2002). As shown by Ziolkowski and Fokkema (1986), this loss of energy is frequency dependent as higher frequencies are absorbed more rapidly than lower frequencies. Thus, as the depth of investigation gets deeper, the ability to image features is reduced as higher frequency components, that could better resolve geologic features, become weaker and could ultimately be obscured by lower frequency components. It is therefore important to study absorption and compensate for its effects in seismic data (Dasgupta and Clark, 1998). Generally, enhancement of weaker signals embedded in lower frequency components and

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background noise is an important step that must be carried out during seismic data processing (Ziolkowski and Fokkema, 1986; Sajid and Ghosh, 2014).

Despite intensive mitigating efforts to reduce noise and enhance weaker signals during seismic acquisition and processing, removing noise from seismic data, as well as spectral enhancement, is an important step during seismic data interpretation for accurate subsurface characterization. Consequently, various algorithms and workflows are important components of standard industry interpretation software aimed at improving seismic data quality prior to interpretation. By attenuating the residual noise and enhancing weaker signals, the results of subsequent interpretations are much facilitated and improved (Yilmaz, 2001; Chopra et al., 2010).

In this paper, we discuss the impact of seismic data conditioning through integration of noise cancellation and spectral enhancement workflows that improved data interpretability and opportunity capture for a deep-seated opportunity within an NNPC/MPN Joint Venture (JV) field offshore Niger Delta. The noise expression workflow was applied to reduce impact of post-processing residual coherent and random noise in the seismic data, whereas spectral enhancement algorithm was applied to increase contribution of frequencies with a weaker signal, thus improving resolution and frequency content of the seismic data.

FIELD OVERVIEW

The field of interest is located in an NNPC/MPN JV operated shallow water block, about 45 km offshore Niger Delta and at water depth of about 18 m (Figure 1a). It is a mature field with 12 known reservoirs where six are developed with 38 producers and 7 gas injectors. Reservoirs are faulted rollover anticline, whereas for some reservoirs, stratigraphic pinch-out creates traps.

The environments of deposition for the producing reservoirs range from fluvial to tidal and to shoreface. The facies are an alternating sequence of sand and shale. Reservoir drive mechanisms vary from water drive to combination drive (water influx combined with gas injection). The prospect under study, Prospect UY1-Deep, is a deep-seated opportunity at depths ranging from about 1300 ft to 1800 ft. It lies within the Lower Tortonian (Tor 2) interval and below current production interval. The prospect is a three-way fault dependent high side closure (Figure 1b) with potential for stacked reservoirs.

The seismic database for the field consists of streamer 2D and 3D, and Ocean Bottom Cable (OBC) 3D reflection seismic data, as well as several derivative volumes (Amidu et al., 2017). The datasets have been processed and reprocessed (in time and depth) into various seismic classes and angle stacks (Full, Far, Mid, and Near stacks). Earlier interpretation in the field, which identified the prospect, used streamer data. OBC data was collected in 2010 to enhance development of existing fields and support exploration objectives. It was demonstrated that OBC data improved imaging quality, and wells tied better in terms of positioning and amplitude strength relative to the streamer data. Hence, OBC data have been heavily integrated into interpretation efforts in the study area, which included subsequent re-evaluation of the prospect. However, issues such as poor imaging towards eastern crest of structure implies the prospect could not be completely de-risked. With advent of Full Wave Inversion (FWI) technology, the OBC data was re-processed using the FWI method and the data was integrated into subsequent prospect re-evaluation. Generally, the FWI seismic processing generated clearer images by resolving

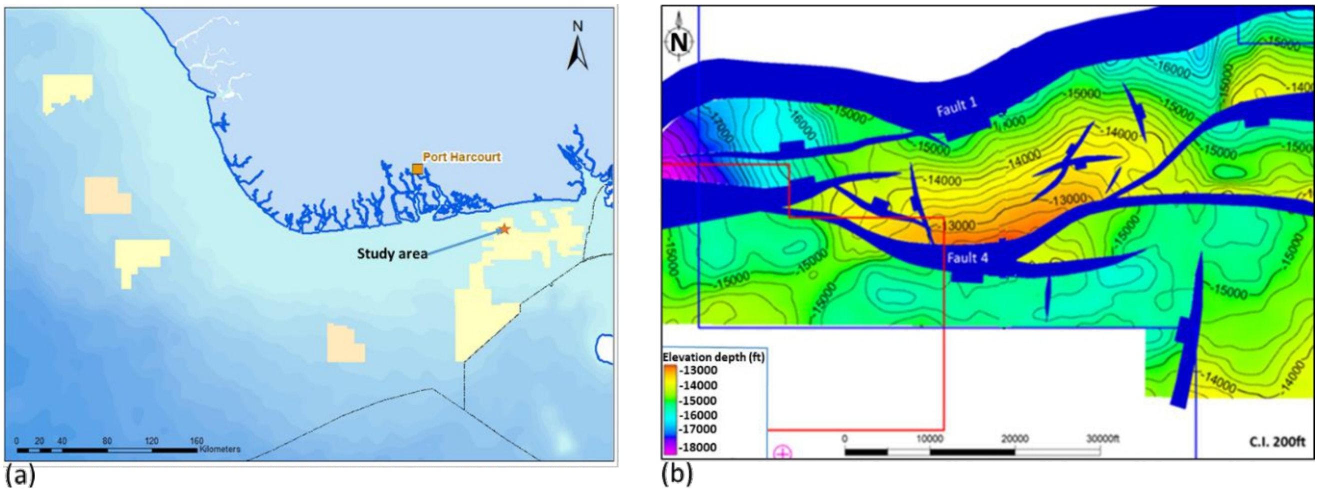


Figure 1: (a) Sub-regional map of Niger Delta showing location of the study area; (b) A depth structure map for the Uy1-Deep prospect

velocity anomalies. However, around the UY1-Deep prospect area, seismic imaging issues persisted as data was relatively noisy and higher frequency signals were attenuated. Thus, prior to seismic interpretation, seismic data conditioning workflows were applied to the FWI volumes. This helped to improve the seismic data quality, and, overall, it improved the technical impacts of integration of FWI volumes into the prospect maturation work process.

SEISMIC DATA CONDITIONING

The workflows that were used in this study are a part of the data conditioning modules of a commercially-available software. Detailed description and practical applications of the data conditioning workflows have been presented by previous authors (McArdle et al. 2014; McArdle and Paton, 2014; Gilani and Gómez-Martínez, 2015; Wooltorton et al., 2017). Initial stage of the data conditioning for the FWI depth volume was to apply noise cancellation algorithm, the result subsequently served as input to the spectral enhancement workflow. For the noise cancellation workflow, to attenuate coherent noise, structurally oriented finite impulse response median hybrid filter was applied, whereas residual random noise in the seismic data was targeted through iterative application of an edge-adaptive tensor diffusion filter. The use of structurally oriented adaptive filters was to improve reflector continuity by smoothing along events, while simultaneously identifying and preserving real discontinuities such as stratigraphic terminations and faults (McArdle et al., 2014). Moderate sizes of noise cancellation filters were considered adequate for attenuating noise and thus improving signal-to-noise ratio, without introducing artifacts into the seismic data.

For the spectral enhancement process, the algorithm involved the use of constant bandwidth Gabor filters for the frequency shaping which were automatically parameterized in terms of central frequency, bandwidth and scale (McArdle and Paton, 2014; Gilani and Gómez-Martínez, 2015). The process improved vertical resolution of the seismic data, by maximizing the mean frequency and the bandwidth. The spectral enhancement was carried out after noise attenuation to prevent re-introduction of noise into the data conditioned volume (McArdle et al., 2014).

RESULTS AND DISCUSSION

Figure 2 shows seismic sections through the FWI depth seismic volume before and after applying noise cancellation and spectral enhancement workflows. A careful comparison of the two sections reveals that the background noise was relatively suppressed and the signal was enhanced. For example, the observable sub-vertical oriented striations in the original volume (Figure 2a), especially as could be seen in the lower section, are less observable in the de-noised FWI data (Figure 2b). Also, amplitudes are relatively laterally continuous and better gained on the conditioned data compared to the original data, especially in the region between the two bounding regional faults. This helped to enhance interpretability and to reduce ambiguity in seismic data interpretation as reflective features that were relatively difficult to identify on the original seismic data were better identified on the conditioned data. Generally, the conditioned seismic data revealed increased level of detail compared to the original volume, which aided overall seismic interpretation process.

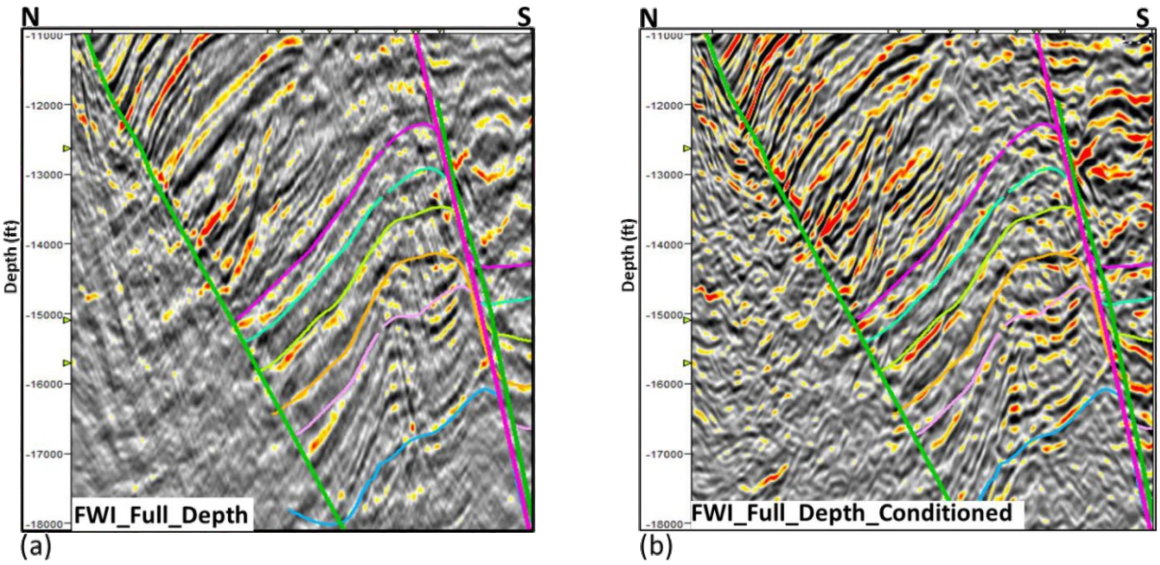


Figure 2: Seismic sections through (a) the original FWI volume and (b) conditioned (de-noised and spectrally enhanced FWI volume) in the prospect area.

Figures 3 shows example of seismic attribute extractions draped on a depth structure map, using the original seismic data (Figure 3a), in comparison to equivalent structure map with attribute extractions from pre-conditioned seismic volume (Figure 3b). Technical impacts of seismic data conditioning in better characterizing the prospect is very well observable. Whereas it was difficult to analyze trends and possible reservoir sand distribution in the extractions from the original data; by gaining the amplitude and suppressing noise, the signal-to-noise ratio was improved such that amplitude variations were observable, and these were successfully used to interpret sand fairways and possible reservoir sand distribution in the prospect area. As shown in Figure 3b, observed sediment input fairways were oriented NW-SE.

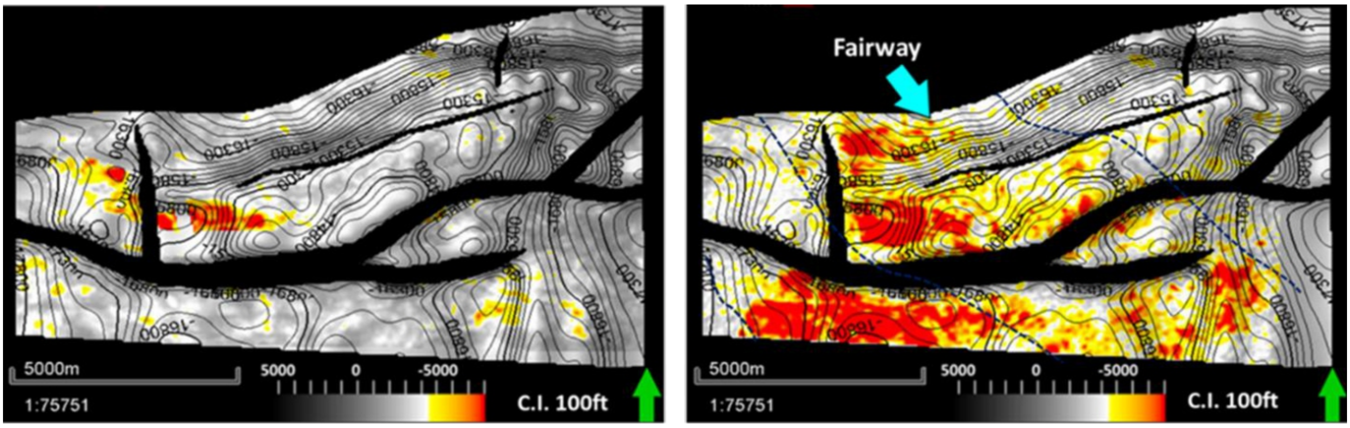
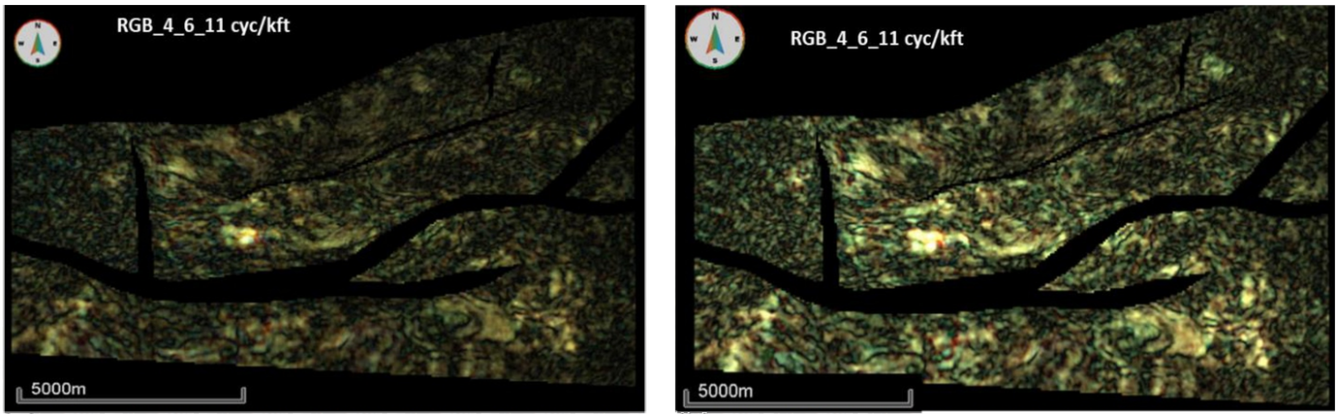


Figure 3: Example of attribute extractions for the original seismic data in comparison to extractions using the conditioned seismic data: (a) Depth structure map with minimum amplitude extraction using the original FWI volume (b) Depth structure map with minimum amplitude extraction using the conditioned volume.

To further de-risk the UY1-Deep prospect, spectral decomposition with color blending, using the RGB (red, green, blue) color-blending method, was carried out. As shown by McArdle et al. (2014) and Amidu et al. (2020), integration of spectral decomposition in prospect evaluation can increase the chance of technical and economic success, as it enables improved visibility of subtle geologic features at resolutions beyond what are possible with the conventional seismic attributes. The approach of Amidu et al. (2020) was used for the frequency decomposition and the color blending. Figure 4 shows examples of RGB blended frequency data draped on the same horizon that was used for the structure maps in Figure 3, using the FWI depth volume before (Figure 4a) and after (Figure 4b) the seismic data conditioning. Improved level of details of channel sand distribution could be observed generally in the spectral decomposition results beyond observable details in the attribute extractions. Nevertheless, as was the case for the seismic attribute analysis, comparing Figures 4a and 4b shows that integration of data conditioning workflows enabled clearer visibility of subtle geologic features and



(a) (b)

Figure 4: Example of horizon-based RGB color blend of frequency volumes that were derived from spectral decomposition using (a) the original FWI depth volume, and (b) Pre-conditioned FWI depth volume.

overall improved characterization of UY1-deep prospect.

SUMMARY AND CONCLUSION

We present technical impacts of an integrative application of spectral enhancement and noise cancellation workflows for improved interpretation of a deep-seated opportunity in a shallow water field offshore Niger Delta. Generally, UY1-Deep structure was interpreted to be a SW-NE trending faulted ridge. Three reservoir intervals were evaluated with cumulative thickness of 2677 ft, and average NTG (net reservoir sand to gross thickness) of 25%. Trap was a high side fault dependent trap with lateral stratigraphic limits. Observed sediment input fairway was oriented NW-SE, and was dominated by moderate amplitude, and semi to discontinuous seismic facies. Environment of deposition was interpreted to be weakly confined channel complex. When ultimately streamed, UY1-deep was assessed to potentially yield a total enhanced ultimate recovery (EUR) of 97 MOEBs (million barrels of oil equivalent), which was 35% higher than assessed EUR from previous study. Key risks (such as fault seal) and uncertainties (such as reservoir fluid type) remain.

The integration of the workflows allowed us to increase signal-to-noise ratio and enhance the bandwidth of seismic data with attendant improved seismic resolution. This procedure helped to define trends better, leading to more confident interpretations. Overall, seismic imaging and reflection continuity improved due to reduction in seismic noise. Also, weak amplitudes in deep sections were enhanced by careful application of the spectral enhancement workflow. The field example presented illustrates the usefulness of the procedure, and how it could help to redefine prospects, which in some cases could be declared unsuccessful when based on interpretation of seismic data with poor data quality. Nevertheless, integration of seismic data conditioning workflows into the prospect evaluation work process, helped in improving subsurface imaging and significantly de-risking the UY1- deep prospect.

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