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Simultaneous Source, Long-offset, Dual-azimuth Acquisition Offshore Gabon - A Change in Perspective

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Summary

It is well known that imaging of complex regions can be significantly improved with increased illumination in terms of offset and azimuth sampling. In this case study we illustrate how an existing large scale acquisition can be enriched by acquiring a second complementary survey in a targeted area. The second survey was acquired in a direction perpendicular to the first with additional offsets for maximum impact. The long offsets were obtained during a single acquisition pass by utilising a source only vessel positioned ahead of the main source and receiver vessel using simultaneous shooting. The blended data was separated using an annihilation filter approach. In this paper we illustrate the advantages this second survey has brought to the area through improvements in the full waveform inversion velocity model and enhanced illumination for imaging the deep structures.



Introduction

Gabon is an exciting new area of opportunity being one of the last uncharted areas of the West Africa Atlantic Margin. During 2014/2015 a very large, multi-client, survey of 25,000 km² was acquired offshore Gabon using a broadband, variable-depth, streamer approach (Soubaras, 2010) with 10 km streamer length. The survey has given a good understanding of the geological history and imaging of the pre-salt in the area, and the overall, complex, structural development of the region.

To further enhance the imaging of such a geologically complex area, an additional acquisition of 2500 km² was conducted during 2016 which offered an alternative and supplementary view of the data. When combined with the original survey, this acquisition provided both a dual azimuth aspect, to improve illumination of the subsurface, along with longer offsets up to 14 km. These two aspects provided valuable additional information to the depth model building for both the tomography and full waveform inversion (FWI). To maximise efficiency the survey was acquired using two vessels and simultaneous shooting to obtain the longer offsets. Energy relating to the two sources was separated prior to the main processing flow.

Motivation

The objectives of the Gabon acquisitions were to provide both a structural image of the larger area and more focussed studies of the major geological interests including the Dentale (pre-salt) formation. The major challenges in the area were the presence of complex salts and carbonates which attenuated energy and influenced the imaging in the pre-salt sections.

The original survey was designed to maximise imaging over the full 25,000 km² using the latest modelling techniques, experience and acquisition equipment (Firth, 2016). The sheer size of the survey meant that both extensional and compressional halokinetic domains are covered, along with the complex transitional zones that connect them. This offered a major challenge to both processing and model building, which was overcome with the latest model building techniques including, amongst others, multi-layer tomography and FWI.

The new survey design called for the same variable-depth streamer profile but with offsets up to 14 km. The “long” offsets brought additional information to the FWI with deeper penetration into the section. The survey was also acquired perpendicular to the direction of the original acquisition to provide additional illumination of the salt and pre-salt structures.

New acquisition

In order to acquire the desired offsets, an additional source vessel was deployed some 4 km ahead of the streamer vessel (Mensch et al. 2016). The first source vessel generated the “short” offsets up to 10 km and the second source vessel the “long” offsets from 4-14 km. Figure 1 contrasts the original acquisition configuration (Figure 1a), with the new one (Figure 1b).

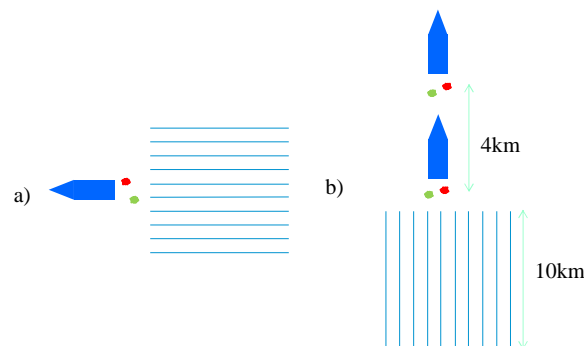


Figure 1 a) Original offshore Gabon acquisition; b) new, dual-azimuth, long-offset acquisition



To avoid having to make two passes over the survey area, these data were acquired using simultaneous source shooting, whereby the sources from both vessels fired at pre-determined times. This meant that blended shots were produced, with an overlap in the seismic record from both sources. To acquire this data the two vessels' navigational systems were aligned such that each fired on the pre-determined shot positions. The timing of the long offset source was then pseudo-randomised to control the overlap of the energy between the long and short offset data. Figure 2a shows an example of the data, where the short and long offset arrivals can be clearly seen.

Once acquired, energy originating from each source was separated, or de-blended, using an annihilation filter approach (Rohnke and Poole, 2016). This method works using knowledge of the timing between the two sources to decouple the short and long offset energy in the sparse tau-p domain. The annihilation filter attenuated the coherent energy in an iterative fashion producing the opposing source's energy. Figure 2b demonstrates this technique on shots which have been duplicated and aligned to their correct timing for the short and long offset data.

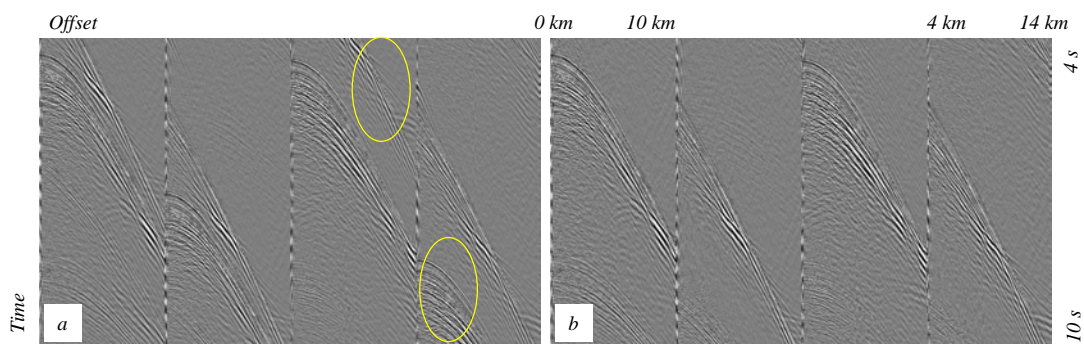


Figure 2 Duplicated shots: (a) before, and (b) after deblending.

Dual Azimuth FWI and the benefit of longer offsets

FWI is a key step in model building and was used to help derive a high-resolution TTI velocity model down to top salt. This new FWI benefitted from the additional long offsets of the new data to penetrate further into the sub-surface, along with the dual azimuth information. The new FWI was performed in a similar fashion as for the full 25,000 km² (Xiao et al. 2016) but with the addition of the dual azimuth and long offset data on input. Figure 3b shows the effect of including the long offset and the additional azimuth for the FWI process when compared to Figure 3a where only the original survey information was utilised. The multi-azimuth long-offset FWI enhanced a channel structure with a depth of approximately 75 m (red arrow), which in turn healed the push-down features denoted by the yellow arrows. The perturbation between the two models in Figure 3c clearly highlights the channel structure.

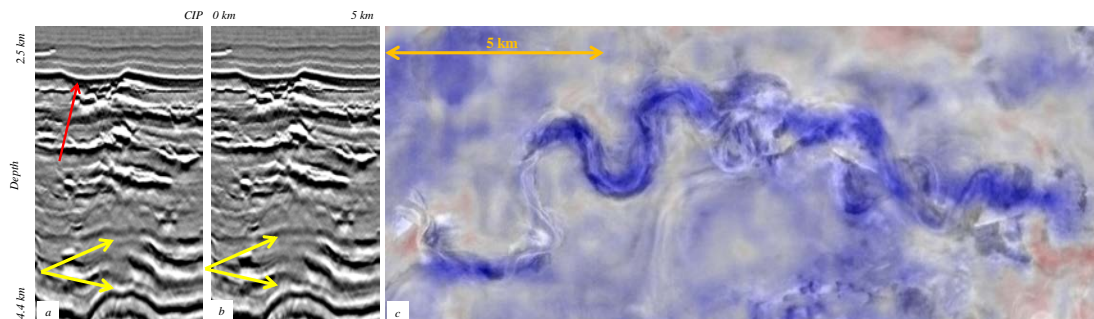


Figure 3 Effect of multi-azimuth long offset FWI: (a) single azimuth FWI, (b) addition of the multi-azimuth plus long offset FWI, and (c) perturbation between single and multi azimuth velocity models highlighting a channel structure.

Dual Azimuth Imaging

The primary objective of the dual azimuth acquisition was to improve the imaging around and below the salt. Initial review of the two azimuths highlighted the differences in the imaging, particularly around the salt structures and in the pre-salt. The additional information contained in the second azimuth data allowed the salt interpretation to be adjusted prior to the start of the model building process for the dual azimuth data. Figures 4 and 5 show the imaging differences between the azimuths on both common image gathers (CIGs) and stacks. Figure 4a shows gathers from the original acquisition and Figure 4b from the new acquisition. In this case the events in the pre-salt are enhanced in the new acquisition which brings valuable information to the tomography. For the stack images Figures 5a and 5c are the original acquisition, while Figures 5b and 5d are the new acquisition; the steep salt flank highlighted by the yellow arrows is imaged better on the new acquisition in Figure 5b, however, in Figure 5c the layered structure (green arrows) is clearly better imaged in the original acquisition. This highlighted that the azimuths supplemented each other and should be used together. This additional information due to the illumination was used as valuable information during the pre-stack depth model building where the model had been updated using residual moveout information.

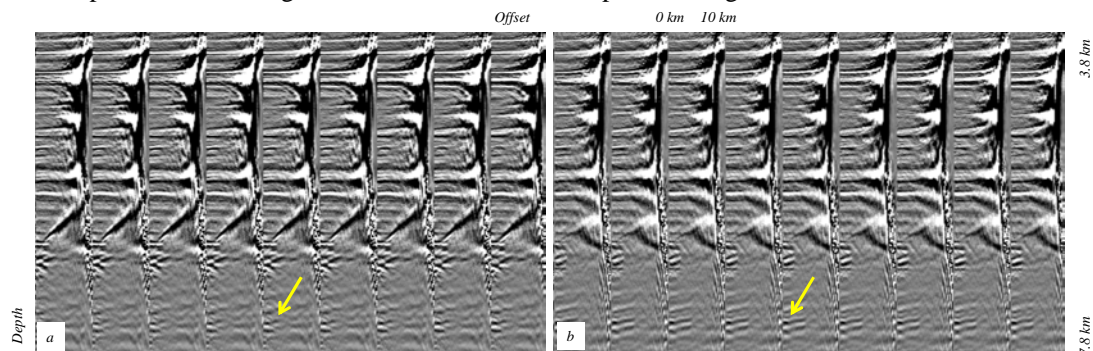


Figure 4 CIG comparison of the different information available to drive the model building between: (a) first azimuth data, and (b) second azimuth data.

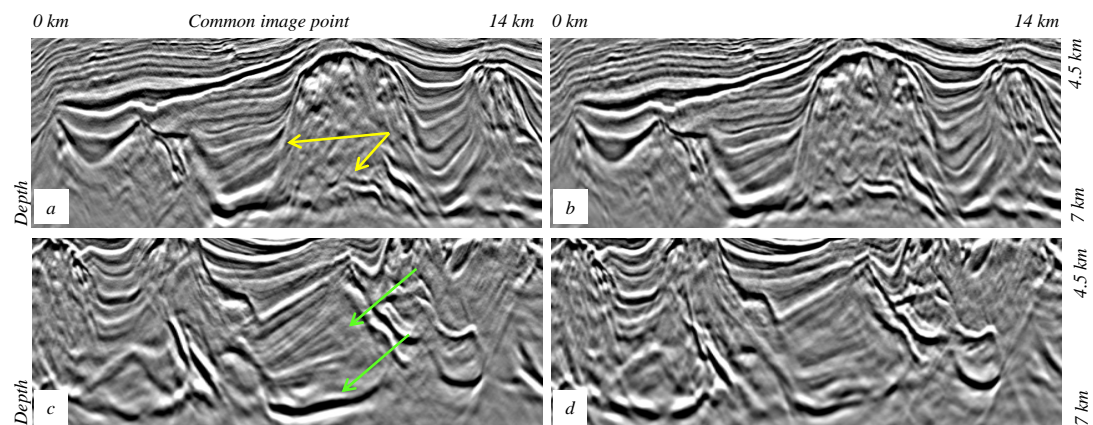


Figure 5 Comparison of imaging between the azimuths using the original acquisition velocity model (a) & (c) original acquisition (inline direction), and (b) & (d) new acquisition (perpendicular direction).

Multi-layer tomography (Guillaume et al. 2013) utilised the multi-azimuth information from the second acquisition and produced an enhanced model particularly where mini-basins exist in the post-salt and in and around the salt structures. Figure 6a shows the stack of the original single azimuth data imaged after the full velocity model building; Figure 6b shows the dual azimuth stack image using the



same velocity model; Figure 6c shows the dual azimuth stack image after the salt bodies were reviewed and a single update of FWI and multi-layer tomography completed. Even at this stage the benefits of the dual azimuth acquisition and processing are giving significant improvements in the target area.

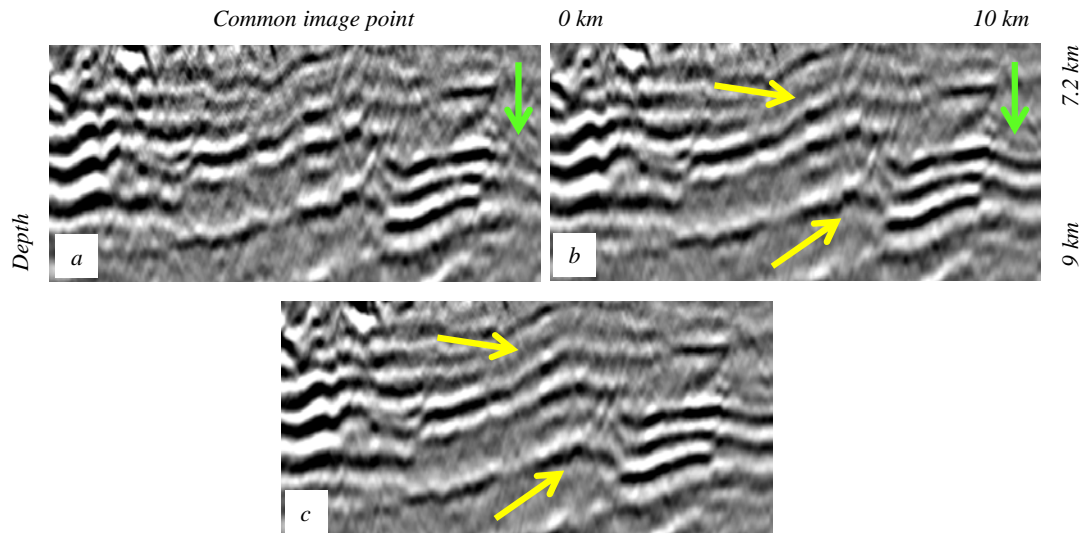


Figure 6 Uplift obtained from a single iteration of 4Hz FWI and multi-layer tomography along with the dual azimuth stacking: (a) first azimuth data with a single azimuth model update, (b) dual azimuth stack after a single azimuth model update, and (c) dual azimuth stack after dual azimuth model update.

Conclusions

This paper demonstrates how we achieved better imaging of a survey offshore Gabon by using a second acquisition that provided additional azimuth and offset information. We built a high-resolution velocity model with additional details by making use of the better illumination from the additional azimuth and offsets.

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