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Rich Azimuth Dual Triple-Source Simultaneous Shooting West of Shetland

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Summary

We discuss the survey planning and provide results from a marine acquisition conducted northwest of the Shetland Islands. The survey was designed to image multiple targets from shallow Tertiary and Cretaceous plays, through to complex fractured Devono-Carboniferous reservoirs. Marine acquisitions are typically conducted along the direction of structural dip. In this case, this was not possible due to the proximity of the survey to the Shetland Islands. In an attempt to address this problem, triple sources were deployed to decrease the spacing between inlines and improve sampling along the structural dip direction. In addition, a second vessel was deployed broadside in a rich-azimuth configuration to increase offset coverage in the y-direction and to help undershoot sills and dykes present in the area. Activating so many sources sequentially would significantly decrease fold and increase noise levels of the data. After careful scenario testing and de-risking, which involved blending and deblending conventional data in various ways, the decision was made to acquire the data with simultaneous shooting. Data after deblending and depth imaging highlight the benefits provided by this rich-azimuth approach.

Introduction

We discuss the survey planning and present results from a novel acquisition in an under-explored area northwest of the Shetland Islands in the North Atlantic (Figure 1a). Positioned over the northern part of the Rona Ridge, the survey was designed to image multiple targets from shallow Tertiary and Cretaceous plays, through to complex fractured Devono-Carboniferous reservoirs (Figure 1b). After the award of significant exploration acreage in the area during the 30th UK Offshore Licensing round, a survey was proposed to cover known Tertiary-Cretaceous discoveries such as Laggan and the recent Glendronach discovery, whilst also identifying potential extension of the prolific Devono-Carboniferous sandstone and Pre-Cambrian fractured basement plays, which are productive at the Clair and Lancaster fields, northeast along the Rona Ridge. One key challenge in this region related to the imaging of several Tertiary volcanic intrusions, linked with the opening of the Atlantic Ocean.

Spatial sampling is key in the design of any seismic survey and should be chosen to optimize illumination and minimize processing artifacts. For towed streamer surveys, acquisition is typically orientated along the direction of main structural dip so that the more complex geology benefits from finer sampling and longer offsets. Here, the main structural dip ran away from the Shetland Islands, northwest to southeast. In this case the objective of acquiring data close to the islands (Figure 1a) was not compatible with the preferred shooting direction, leaving no alternative than to shoot strike to the main structure. We describe a simultaneous shooting rich-azimuth acquisition to mitigate these issues.

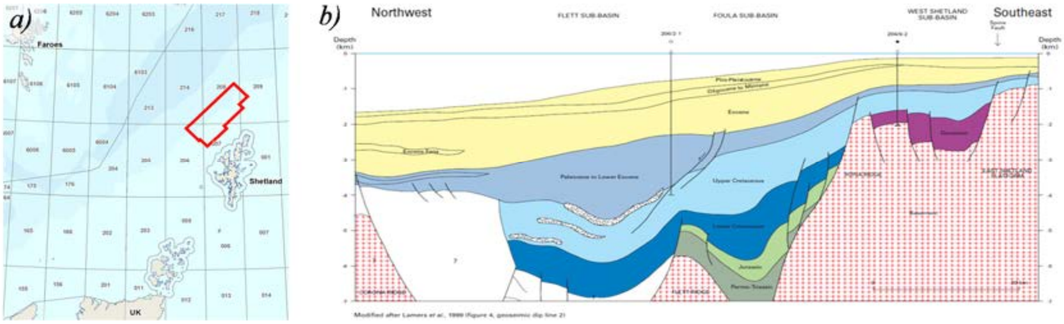

Figure 1 a) Survey location, and b) Geological setting, following Lamers and Carmichael (1999).

Acquisition strategy

One strategy to improve sampling in the crossline direction is to reduce the streamer separation. Unfortunately, this significantly increases acquisition time and cost. A more cost effective approach is to increase the number of sources (Langhammer and Bennion, 2015), which can provide additional source-cable sublines and improve sampling perpendicular to the sailline direction. A second consideration is to increase the maximum y-offset, which can be achieved through multi-vessel acquisition. In this setting, rich azimuths provided by a second vessel had the potential to improve imaging beneath Tertiary volcanics known to be present in the area.

Translating survey objectives into an acquisition design involved scenario testing of several rich azimuth solutions where the source vessel was placed at the front, middle, and end of the cable. The chosen acquisition strategy was determined based on feedback from stakeholders within an integrated geoscience group, taking into account the modelled illumination benefits. It was quickly determined that a triple-source acquisition would be required to improve crossline sampling along the structural dip direction whilst maintaining operational efficiency. Building on confidence from previous deblending experience (Rohnke and Poole, 2016; Peng and Meng, 2016), blended data was simulated, and subsequently separated, to confirm the accuracy of the process. Careful consideration was given to the source firing times to enable optimal deblending of this six-source acquisition proposal.

The chosen configuration utilized a dual-vessel rich-azimuth set-up, each vessel equipped with triple sources as illustrated in Figure 2a. A rose diagram indicating the acquired fold is given in Figure 2b. The sources were towed at 8 m depth with a 33.3 m separation. The streamer vessel towed 12 streamers with a 100 m separation and 7950 m length, at a constant depth of 11 m. The source vessel was positioned 1200 m broadside of the streamer vessel, halfway along the streamers. As well as maximizing the rich-azimuth contribution to the stack, the source vessel positioning also provided a difference in apparent dip between arrivals from both vessels, which assisted the deblending.

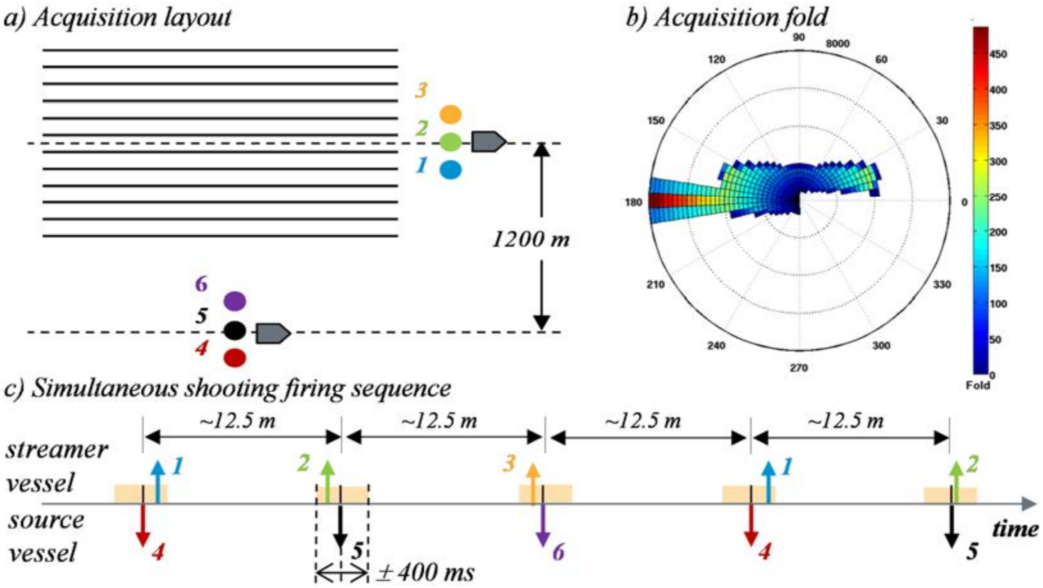

Figure 2 *a) Acquisition layout, b) Acquisition fold, and c) Simultaneous shooting firing sequence.*

With six sources deployed at sea, sequential activation would result in a low fold, poorly sampled dataset. As such, the shooting strategy was adapted to fire the sources more frequently (12.5 m flip-to-flop-to-flap shotpoint interval) in order to preserve seismic fold for all offset/azimuth classes, as well as increasing operational efficiency. In addition, the decision was made to fire sources from both vessels simultaneously, using pre-defined optimized firing times with dithering in the range ±400 ms. The resulting shooting pattern is summarized in Figure 2c. Such an acquisition strategy required an up-to-date acquisition system which relied on continuous recording technology for proper handling of the seismic records and guaranteed the integrity of the seismic data.

Figure 3 shows raw data from the acquisition. This 8 second trace section shows the level of contamination between early narrow (*S1*) and wide-azimuth (*S4*) arrivals, as well as contamination coming from the activation of the subsequent shots (*S2* and *S5*). The interference between the two early shots is of a similar amplitude level and is conflicting in dip. This conflict in dip reduced the contamination between these sources post-stack, and also helped the deblending of these arrivals. The two subsequent shots (*S2* and *S5*) are much stronger in amplitude than the underlying weak signal, and have similar kinematics; particularly at the apex of *S5*. It was anticipated that separation of the later shots would provide the biggest challenge to the deblending.

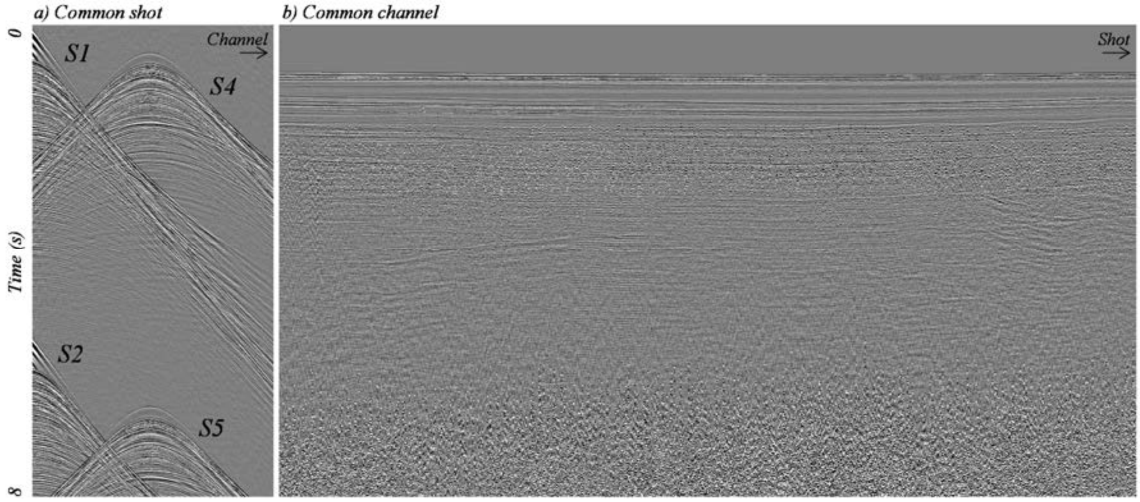

Figure 3 *Raw recorded data, aligned on S1 firing time. a) Shot gather, b) Common channel gather.*

Deblending

The data was deblended using a modified form of a complex wavelet transform driven inversion following Peng and Meng (2016). The modification involved changing the inversion approach to include a continuous recording reblending step, so as to deblend all six sources in one step. Based on the notation of Peng and Meng (2016), the methodology involved an L1 minimisation of the following equation:

$$d_c = \begin{bmatrix} R_1 & \dots & R_N \end{bmatrix} \begin{bmatrix} S & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & S \end{bmatrix} \begin{bmatrix} H^T & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & H^T \end{bmatrix} \begin{bmatrix} m_1 \\ \vdots \\ m_N \end{bmatrix}$$

where d_c is the continuous recording blended input data consisting of N sources, m_n is the model of source n in the high angular resolution complex wavelet transform domain, H^T is the reverse high angular resolution complex wavelet transform operator, S is an interpolating operator to handle irregular grids and aliasing, and R_n is the reblending operator of source n. The reblending operator involved an accumulation of trace segments corresponding to the firing of each shot into a single continuous recording trace of several hours in length.

Figure 4 shows stack data before and after deblending along with differences, including time-squared gain correction. The difference sections highlight that the cross-talk from the early contamination is relatively weak compared to the cross-talk in the deep section, which is approximately 30 dB stronger than the underlying signal. Nevertheless, the deblending results show that deeper events have been revealed through this deblending process.

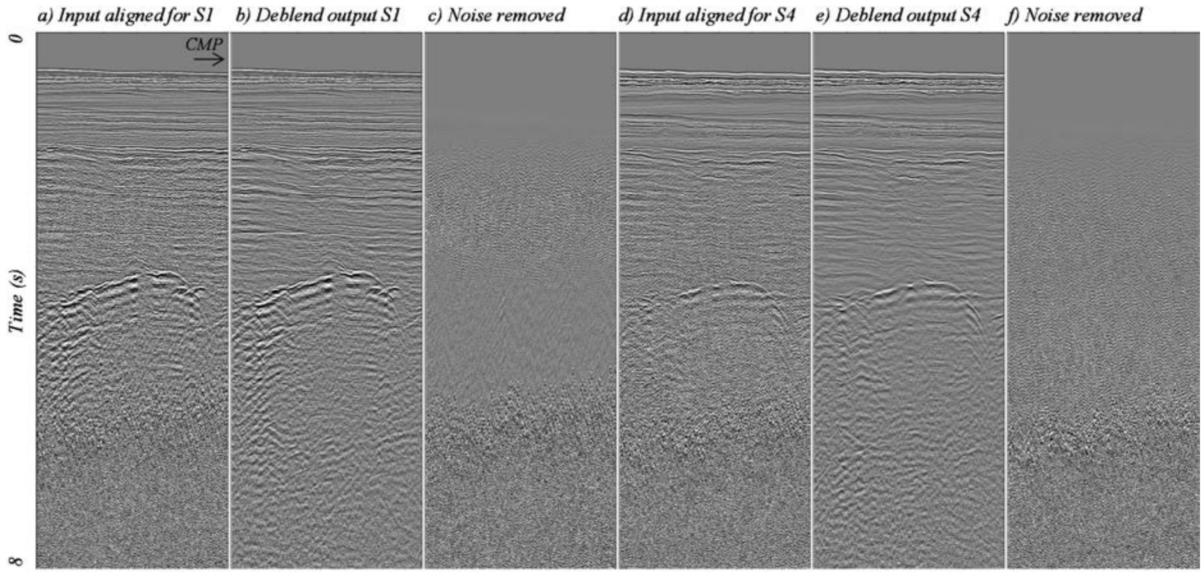

Figure 4 *Stack sections before and after deblending along with noise removed.*

Data analysis

A sailline based processing sequence was developed to allow data received from the vessel to be processed as quickly as possible. The pre-processing sequence consisted of: common channel deblending (following Peng and Meng, 2016; described above), swell noise attenuation, debubbling, 3D simultaneous source and receiver deghosting (Wang et al, 2014, Poole et al., 2015), model-based water-layer demultiple (Wang et al., 2011) and Radon demultiple. An initial pre-stack depth migration velocity model was used as input to a low-frequency full-waveform inversion. For imaging, a one-way wave equation migration algorithm was used in order to take advantage of being able to migrate each shot as soon as it had completed the full pre-processing sequence. The narrow- and wide-azimuth datasets were migrated separately in order to fully assess the impact of each to the final image. Initial imaging results were available 10 days after the last shot being fired.

Figure 5 shows a comparison between images coming from the narrow-azimuth data with the combined rich-azimuth data. When the additional azimuth is included we observe improvements in illumination and continuity of the deep reflectors, due to the increased y-offset contribution. Figure 6 shows a comparison between the described acquisition and a vintage product available in the area. A similar uplift in the continuity of deep reflectors can be appreciated with this vintage comparison.

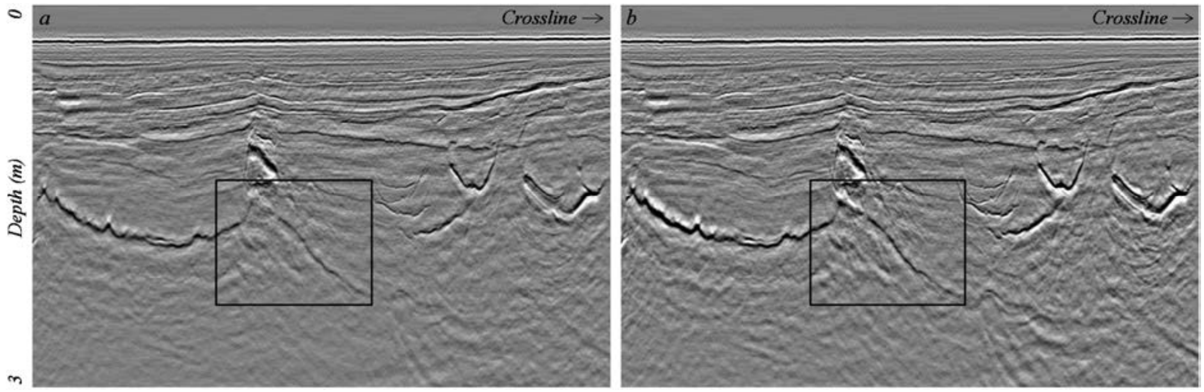

***Figure 5** a) Subline through narrow azimuth volume, and b) Rich-azimuth volume.*

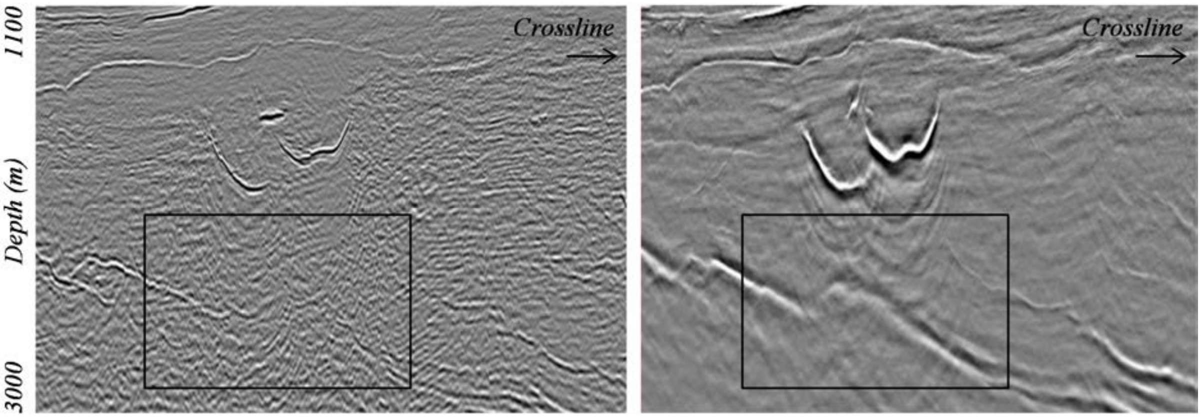

***Figure 6** a) Subline through legacy volume, and b) Rich-azimuth volume.*

Conclusions

We have presented a rich-azimuth, dual-vessel, triple-source, simultaneous-shooting acquisition deployed west of the Shetland Islands. This approach was used to maximise sampling along the direction of main structural complexity and to undershoot Tertiary volcanic intrusions. Despite the highly blended nature of the data, we have demonstrated that the strong cross-talk associated with this type of acquisition can be removed. Imaging results confirm the value of the rich-azimuth data.

Acknowledgements

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