

IMAGING RICH AZIMUTH TOWED STREAMER DATA WEST OF SHETLAND

H. Moore¹, S. Drummie¹, E. Kaszycka¹, G. Poole¹, K. Cichy¹, E. Blaszczyk¹, D. Montanino¹, U. Maka¹, H. Kerrison¹

¹ CGG

Summary

We discuss the processing and imaging challenges relating to a marine seismic survey acquired northwest of the Shetland Islands. The proximity of the survey to the islands forced the acquisition direction to be strike to the subsurface geology. A shooting vessel provided wide azimuth data to illuminate in the dip direction, and triple sources increased crossline sampling. We show how 3D source designature and source/receiver deghosting were required for this wide azimuth data. For demultiple we illustrate how utilizing narrow azimuth data in water layer multiple modelling was crucial for the wide azimuth multiple prediction. In addition we highlight the benefits of a wave equation deconvolution based approach in this shallow water setting. For velocity model building we show how using time-lag full waveform inversion helped resolve the specific challenges created by the geological setting. Finally we demonstrate how that imaging was aided by the use of least squares migration and the inclusion of the wide azimuth aspect.

Introduction

We discuss the processing and imaging challenges of a geologically complex area located northwest of the Shetland Islands in the North Atlantic. Positioned over the northern part of the Rona Ridge, the survey objectives involved imaging several targets from deep complex fractured Devonian-Carboniferous reservoirs to shallow Tertiary and Cretaceous plays. Covering the Laggan and Glendronach Tertiary-Cretaceous discoveries, the survey also imaged Devonian-Carboniferous sandstone and Pre-Cambrian fractured basement plays, which are productive at the Clair and Lancaster fields. The geological setting consisted of a hard seabed, igneous intrusions, and a highly variable basement, all contributing to a challenging geophysical environment, where advanced processing techniques enhanced by rich azimuth data combined to extract more subsurface information than before in this prospective area.

The acquisition involved deployment of two vessels, each equipped with triple sources, which was driven by geologically based challenges as well as the physical location of the survey. The proximity of the survey to the Shetland Islands forced the acquisition orientation to be sub-optimal, parallel to the geological strike direction. Poole et al. (2019a) described the reasoning behind the configuration, with the acquisition layout being shown in Figure 1a. Compared to a standard single vessel configuration, this approach provided improved dip sampling, plus richer azimuthal coverage to improve the illumination below and around the volcanic sills/dykes.

Building on the results of Poole et al. (2019a), we will briefly touch on the deblending strategy, and then move on to describe how the pre-processing, velocity model building, and imaging flows were carefully designed to overcome the challenges presented by this dataset.

Deblending

Figure 1b shows the heavily blended nature of the data due to four shots (S1/S2/S4/S5) overlapping within one record. The ability to separate the arrivals from each of the sources accurately was paramount to the success of the survey. The inversion driven approach of Peng and Meng (2016) was modified to separate all six sources in one go by including a continuous recording reblending step (Poole et al., 2019a). Figures 1b to 1d show results of the deblending for a shot gather. We observe minimal residual crosstalk in the result, despite the complication of having four shots to separate.

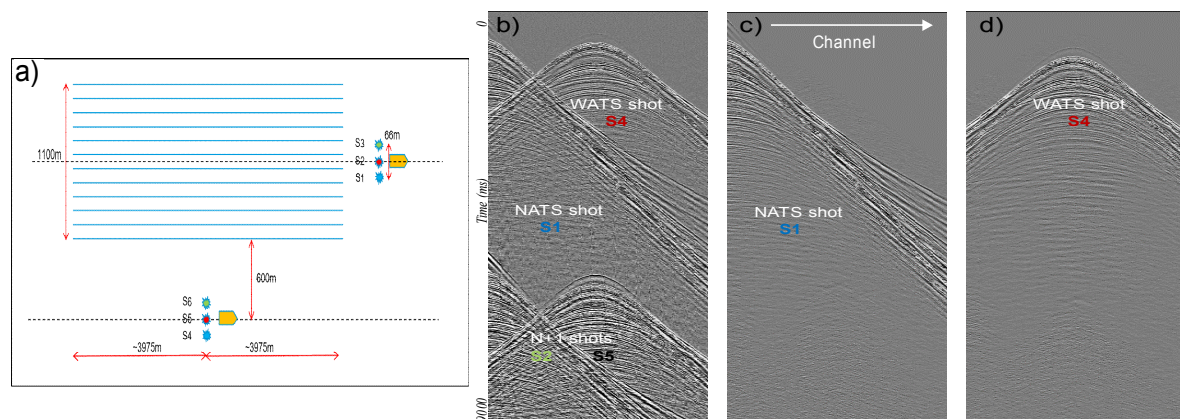


Figure 1 a) Acquisition layout. Shot gathers: b) before deblending, c) S1 after deblending, and d) S4 after deblending.

Pre-Imaging

Due to azimuthal variations arising from this wide azimuth configuration, a 3D approach to designature and deghosting was essential. This was facilitated via a 3D sparse tau-p algorithm, which performed simultaneous source designature and receiver deghosting utilizing notional sources derived from nearfield hydrophone data (Poole et al., 2015). Figure 2 compares applications of 2D and 3D designature and deghosting on a wide azimuth shot gather. Heavy ringing can be observed in the 2D implementation, Figure 2b, which was avoided through use of the 3D algorithm, Figure 2c. The amplitude spectrum in Figure 2d shows how the 2D approximation over-boosted frequencies at 70 Hz where the 2D model expected the ghost notch.

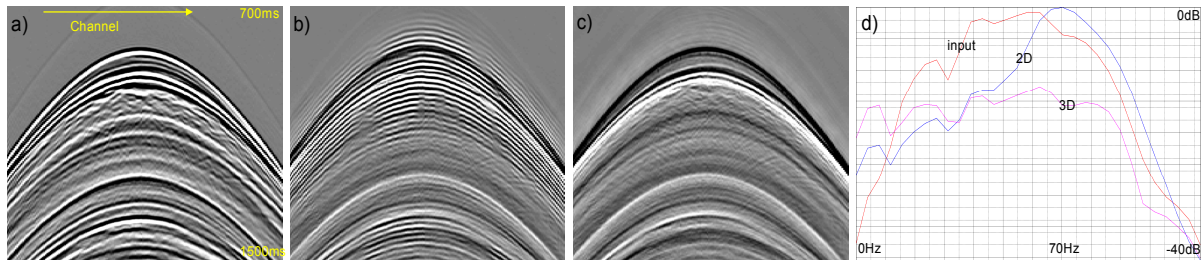


Figure 2 Wide azimuth deghosting, shot gathers: a) input, b) 2D deghosting vs c) 3D deghosting, showing greatly reduced ringing, and d) amplitude spectra.

A second challenge was to achieve accurate multiple modelling for this wide azimuth configuration. It is well known that the availability of short offset data is necessary for the modelling of multiples at longer offsets. For this reason, narrow azimuth (NAZ) data was used as input to the wide azimuth (WAZ) water layer based multiple modelling (Wang et al., 2011). Figure 3 shows a wide azimuth common channel display for input data and multiple modelling results with and without use of the narrow azimuth data. The multiple model with use of the narrow azimuth data has improved spatial continuity and bears a closer resemblance to the multiples present in the input data.

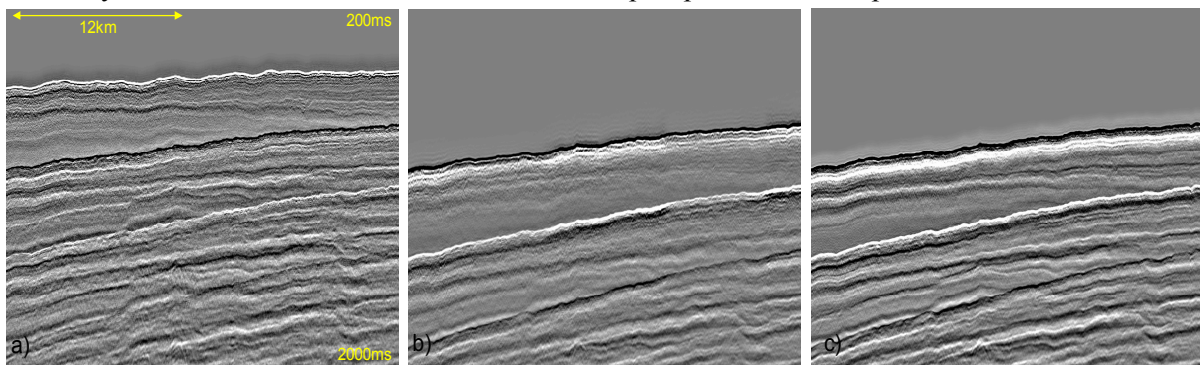


Figure 3 WAZ common channel showing: a) input, b) multiple model using WAZ only, and c) multiple model using NAZ and WAZ for modelling.

The multiple modelling had further challenges due to the extremely hard water bottom in this area which reflected back the vast majority of energy released by the sources leading to recording of very high amplitude multiples overlapping low amplitude primary signal. The shallow water bottom (in some areas less than 100 m) added further difficulties, producing many orders of multiples with short periodicities that overlapped at low frequencies. These challenges required a highly accurate demultiple technique and as such the approach of multi-sail line 3D deconvolution imaging (following Poole, 2019b) was used. This method created a reflectivity (Figure 4b), which had much improved clarity and resolution over the primary image (Figure 4a). The reflectivity was used to generate a multiple model that was adaptively subtracted from the input data using a complex wavelet transform. Figure 4c shows the input, Figure 4d shows a model based water layer demultiple, which has significantly more residual multiple than the deconvolution imaging method result in Figure 4e. The final processing used the multiple models from both solutions mentioned above.

Velocity model building

With only limited coverage of 3D and 2D legacy seismic in the area and a localized selection of available wells, the initial velocity model had to be built from the ground up, via 1D picking combined with anisotropy derived from wells and an interpreted dip field. Gravity and magnetic data was acquired over the survey area, and was used to add information to the interpretation of the obscured sub-sill basement. The presence of a vast quantity of shallow volcanic sills made improving the velocity model a challenge. The high velocity (6100 m/s within the sills) gave a strong amplitude contrast, also multiples and diffractions originating from these sills dominated input gathers and masked the diving waves present in the data with significant tuning at low frequencies. Time-lag FWI was utilised (Zhang et al., 2018) as the main algorithm for the update. It proved to be more robust than conventional FWI in the presence of high amplitude variations as the method used measured travel-

time misfits based on cross-correlation coefficients. This prevented anomalous high velocity trends being introduced below the thin sills where a sedimentary velocity was expected, Figure 5.

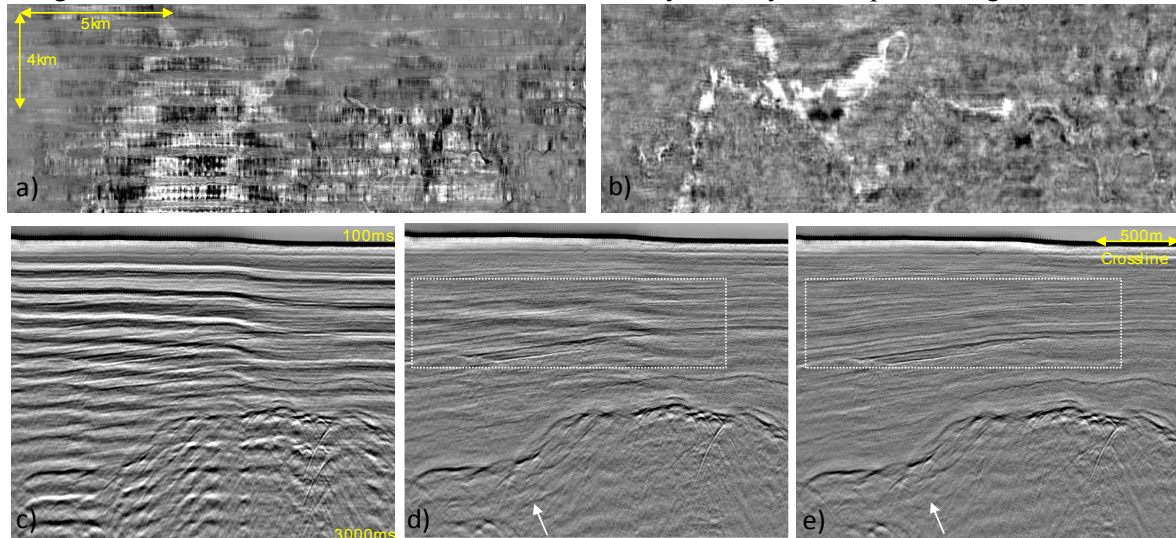


Figure 4 Depth slices located 80 m below seabed: a) conventional Kirchhoff depth migration, and b) deconvolution imaging. Stack sections: c) input, d) water layer demultiple, and e) demultiple using multiple modelling based on the deconvolution image. Residual multiple difference is particularly pronounced at low frequencies, as highlighted by the white box and arrow.

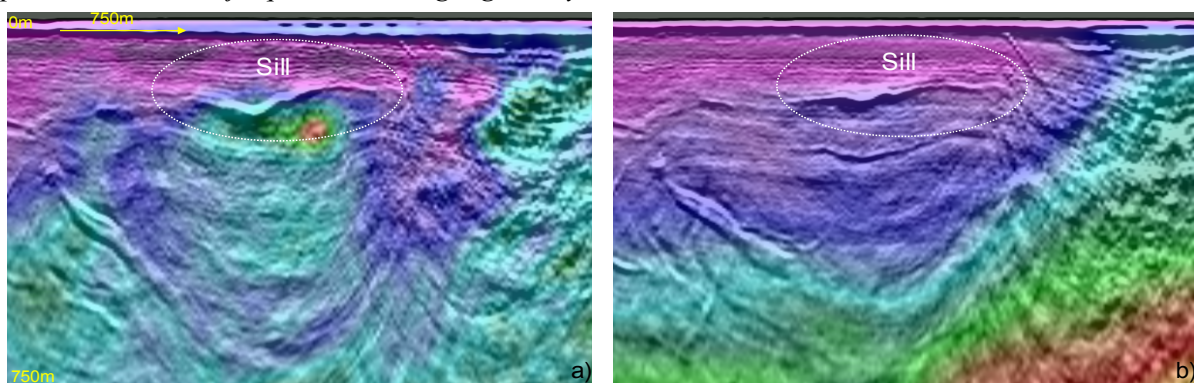


Figure 5 Velocity fields overlaid with migrated seismic for: a) conventional FWI and b) time-lag FWI.

With the underlying sediment trend in place from time-lag FWI, the next challenge was to incorporate the volcanic sills into the velocity model for imaging. The sills varied in thicknesses from 30 m to 500 m, with a spatial extent of up to 4 km². With an approximate velocity of 6100 m/s (based on well information) it was important that these sills were incorporated in the velocity model before imaging. Initial tests involving adding a 30 m iso-pack underneath picked sill tops showed limited improvement indicating the thinnest of sills had minimal effect on the imaging. For thicker sills, where the top and base could be identified, accurate picking and inclusion of the full sill lead to significant improvements in the sub-sill imaging, particularly when using the wide azimuth data.

Imaging

Being able to understand and interpret potential basement plays underneath the volcanic sills was a key aspect of the project. The high velocity contrasts and complex nature of the sills required consideration of several imaging routes to reveal the underlying sediments and faulted basement. Some key features were not illuminated at all by the narrow azimuth data, so the inclusion of the wide azimuth data helped to image these areas, and at the same time improve the overall signal-to-noise ratio (see Figure 6). Additionally Kirchhoff least squares migration (Casasanta et al., 2017) was utilised to improve low illumination areas, and suppress imaging related noise (see Figure 7).

Conclusions

We have discussed the processing and imaging challenges of a shallow water dataset acquired west of the Shetland Islands. The geological complexity and local acquisition restrictions required a complex

acquisition scheme, which included wide azimuth data. This created challenges for the subsequent processing. As well as advanced deblending being necessary to process this data, we have highlighted the value of 3D designature and deghosting for the wide azimuth dataset. In addition, we have shown how it was necessary to use the narrow azimuth data to predict multiples on the wide azimuth data as well as highlighting the benefits of a wave equation deconvolution multiple modelling approach. We have illustrated the value time-lag FWI provided to update the velocity model beneath basaltic sills. Finally we have shown the improvement the wide azimuth data brought to imaging, and how Kirchhoff least squares migration also improved the final image.

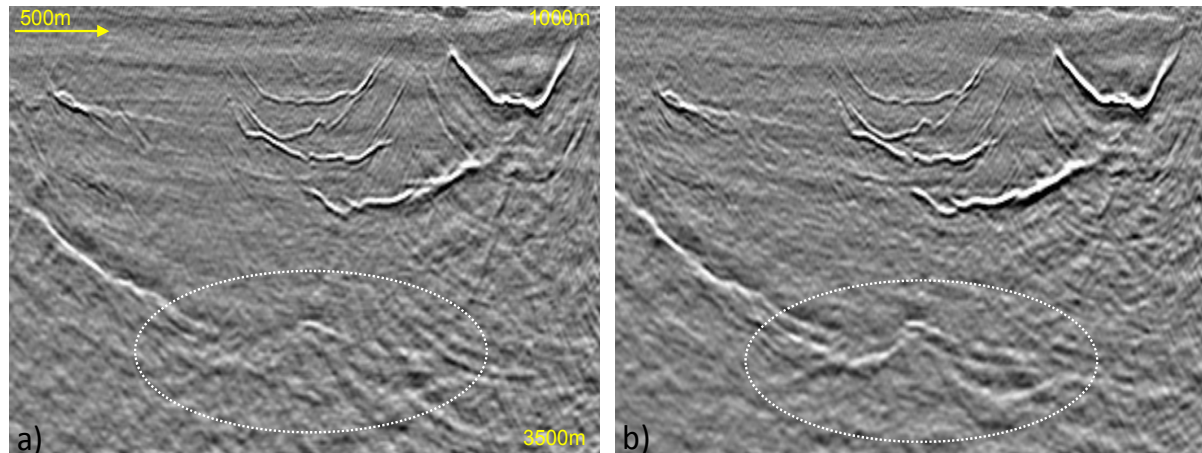


Figure 6 Kirchhoff depth migration - inline: a) narrow azimuth data and b) rich azimuth data.

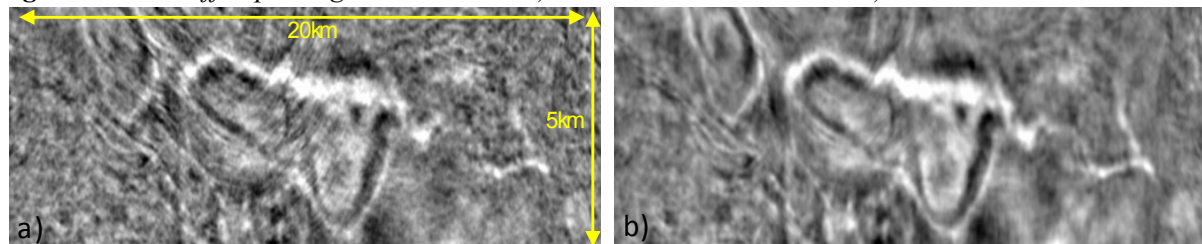


Figure 7 2.5km depth slice comparing: a) Kirchhoff depth migration compared to b) least squares Kirchhoff depth migration.

Acknowledgements

We would like to thank BP, Shell, CGG Multi-Client New Ventures, Marine acquisition and Subsurface Imaging for making this project possible.

References

- Casasanta, L., Roberts, G., Perrone, F., Ratcliffe, A., Poole, G., Wang, Y. and Xie, Y. [2017] Practical benefits of Kirchhoff least-squares migration deconvolution. *79th EAGE Conference and Exhibition, EAGE*, Expanded Abstracts.
- Peng, C. and Meng, J. [2016] Inversion-based 3D deblending of towed-streamer simultaneous source data using sparse TauP and wavelet transforms. *86th Annual International Meeting, SEG*, Expanded Abstracts.
- Poole, G., Wang, P., Ni, Y., Fu, Z. and Siliqi, R. [2015] Nearfield hydrophone driven 3D source designature and deghosting for multi-level source data. *EAGE workshop/forum/local conference - Abu Dhabi*.
- Poole, G., Page, C., James, G., Wombell, R., Mensch, T., Flower, R., Kaszycka, E., Cichy, K., Davies, D., Saxton, L. and Harrison, D. [2019a] Rich azimuth dual triple-source simultaneous shooting West of Shetland. *81st EAGE conference & exhibition*, Extended abstracts.
- Poole, G. [2019b] Shallow water surface related multiple attenuation using multi-sailline 3D deconvolution imaging. *81st EAGE conference & exhibition*, Extended abstracts.
- Wang, P., Jin, H., Xu, S. and Zhang, Y. [2011] Model-based water-layer demultiple. *81st Annual International Meeting, SEG*, Expanded Abstracts.
- Zhang, Z., Mei, J., Lin, F., Huang, R. and Wang, P. [2018] Correcting for salt misinterpretation with full-waveform inversion. *88th Annual International Meeting, SEG*, Expanded Abstracts, 1143–1147.