INTEGRATING FWI AND REFLECTION TOMOGRAPHY TO REJUVENATE LEGACY SEISMIC DATA: AN EXAMPLE FROM THE FAROES-SHETLAND BASIN

A. Castiello[1], G. Venfield[1], J. Beenfeldt[1], E. Mueller[1], J. Khan[1]

[1] PGS

Summary

We present a robust depth imaging workflow that incorporates high-resolution Full Waveform Inversion (FWI) and reflection tomography constrained by geological interpretation. This approach has allowed us to both update the long wavelength and the fine details of the velocity model by a simultaneous combination of eight vintage streamer surveys characterized by a wide range of acquisition parameters. We demonstrate the benefits of this integrated scheme by presenting the results from the West of Shetland area, offshore UK.

Integrating FWI and reflection tomography to rejuvenate legacy seismic data: an example from the Faroes-Shetland Basin

Introduction

It is well documented that upstream exploration budgets have been greatly reduced over recent years. As such, the rejuvenation of legacy data, using state of the art processing techniques is more important than ever. The West of Shetland (WoS) is still an area of great interest and, as such, our vision is to rejuvenate 38 seismic datasets over the larger Faroe-Shetland Basin (FSB) area, through four phases, to provide a single, high quality and seamless dataset. The area is characterized by strong lateral and vertical velocity gradients throughout the section and, therefore, a high-end and robust workflow has been used to capture these trends. High-resolution Full Waveform Inversion (FWI) and reflection tomography, constrained by geological interpretation has been successfully implemented to resolve the imaging challenges. We demonstrate the results of this integrated model building scheme from the initial phase of reprocessing.

Geological Background

The FSB is located between the Faroe and Shetland islands on the NW European Atlantic margin and is a NW-SE orientated deep-water rift basin, consisting of several ridges and sub-basins (Figure 1). The basin has a complex tectonic history and has experienced several periods of rifting in Permian-Triassic, Jurassic, Cretaceous and Palaeocene, followed by thermal subsidence (Smallwood et al. 2004). During the Palaeocene to Early Eocene, the basin was subjected to extensive igneous activity associated with the proto-Icelandic plume and seafloor spreading in the North-Atlantic (White & Lovell, 1997). This resulted in eruptions and the deposition of sequences of basalt lava flows, along with extensive emplacement of subsurface intrusive sill complexes. The Cenozoic is dominated by post-rift thermal subsidence and minor episodes of rifting, uplift and compressional events (Smallwood & Kirk, 2005). The tectonic history has led to thick sedimentary sections with exploration targets at various depths and ages. The predominant targets are turbiditic or marine slope fan sandstones of Palaeocene-Eocene age, fluvial systems and slope fans of Jurassic-Early Cretaceous age and Palaeozoic sandstones around the ridges.

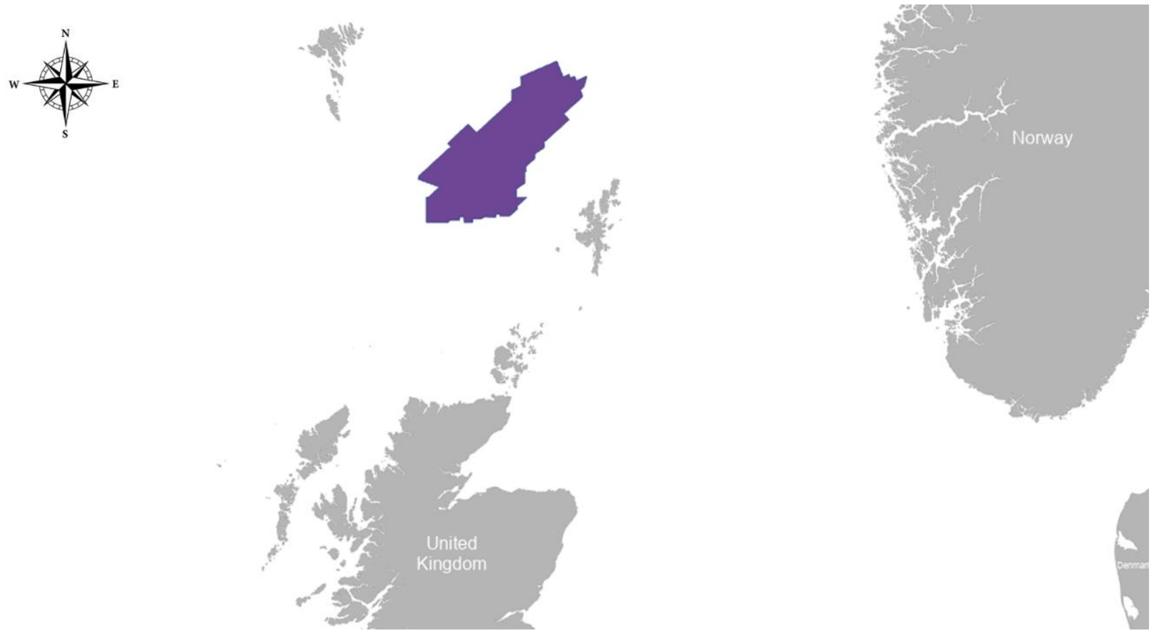

Figure 1 *Area Map. The purple polygon indicates the location of the FSB area.*

Application examples

Phase 1 consists of the reprocessing of eight legacy streamer surveys, acquired between 1995 and 2013. Surveys are both conventional and multi-component and show a large variety of acquisition parameters, including differences in azimuth, source and cable length (varying between 4 and 8 km). Water depths vary between 700 – 1500m and the overburden is characterized by fast Eocene fan deposits, sand injectites, polygonal faults, turbidite deposits and hydrothermal vents. Intra-volcanic reservoirs are encased in high contrast flood plain basalts which makes unconstrained tomographic model building difficult. Intermittent periods of volcanic activity produced varying quantities of intrusive complexes, basaltic lava and volcaniclastic material, which are associated a large range of seismic velocities.

Data passed through a high-end pre-processing workflow which aimed to provide a consistent dataset over the full area for final migration. The emphasis of the velocity model building was to accurately account for the complex overburden using FWI and to focus on the intra-volcanic update using geobodies and reflection tomography to reduce depth uncertainty and generate an enhanced image.

Depth imaging in complex geology, as for this dataset, requires an accurate background model. This controls the kinematic behavior, focusing and positioning during the migration process. To accurately solve for the low wavenumbers, we utilized a FWI implementation with a unique imaging condition that separates the tomography from the impedance kernel (Ramos-Martinez et al., 2016). This reduces the traditional dominance of high wavenumbers when reflections are involved in the inversion (Brandsberg-Dahl et al., 2017). Our FWI process followed a classical multi-scale approach; starting from low to high frequencies and gradually growing the data selection based on the match between the observed and modeled response until most of the data was utilized in the inversion.

The workflow adopted for the intra-volcanic interval included the automatic picking of the volcanics and intrusions as geobodies. The geobodies, once picked were used during the subsequent tomographic updates to constrain the model and allow a targeted high-resolution velocity variations within the intrusions/volcanics and in the background.

Prior to FWI, an initial model was created, strongly constrained by the available well data. Long wavelength reflection tomographic updates were completed in the overburden and anisotropy parameters calculated. As part of the preparation, data was matched to a common reference wavelet, allowing all surveys to be updated simultaneously.

FWI was completed by inverting all surveys simultaneously in several passes, progressively increasing the frequency to 12 Hz. Given the water depth, inverting using refractions and reflections led to a consistent update in the overburden, irrespective of acquisition. FWI has solved the complex velocity variations and reduced the seismic imaging uncertainty as verified by the dense population of well data. Figure 2 shows a depth slice through the overburden of the velocity model after FWI. The velocity varies on a short wavelength and captures the strong and complex velocity variations. The methodology of running FWI across all surveys simultaneously has led to a consistent model across the area, which does not show any footprint.

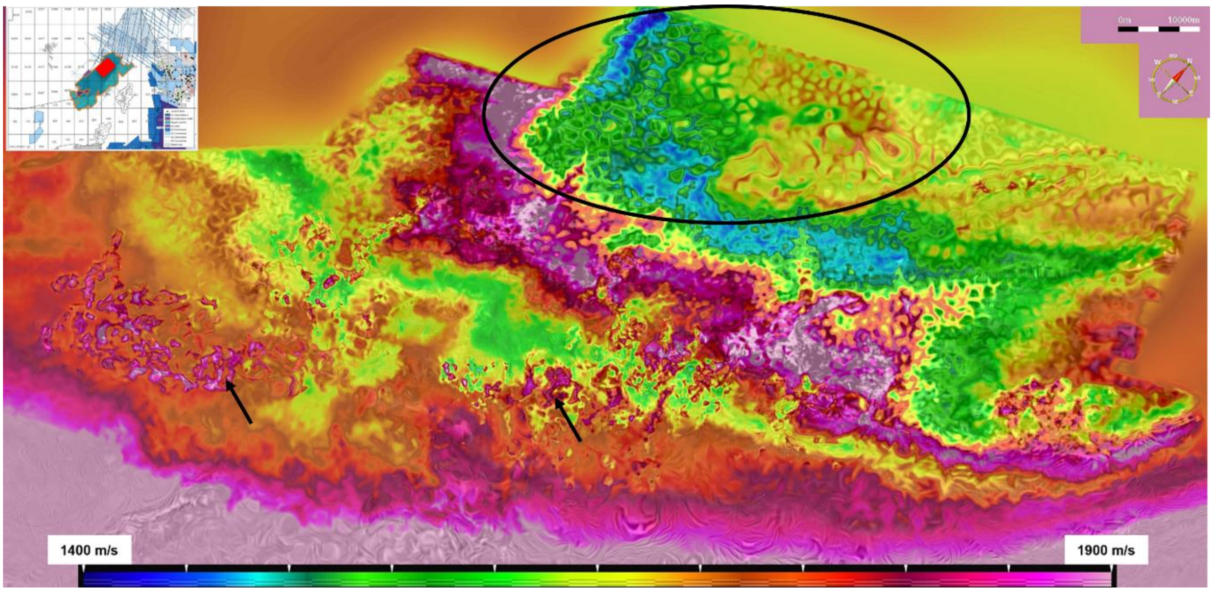

Figure 2 *Depth slice (2000 m) showing the final FWI model with underlying Beam PSDM. The velocity model correlates with sand injectites (some of them indicated by the arrows) and geological structures such as the polygonal faults in the north (in the area within the oval).*

Figure 3 shows the velocity model after the FWI update, overlaid on a Beam PSDM seismic section. The vertical velocity variations in the section have been effectively captured with the associated velocity increase in the very small features like injectites, turbidites, as well as the fast Eocene fan deposits accounted for. These features would be difficult to solve with traditional tomography approaches.

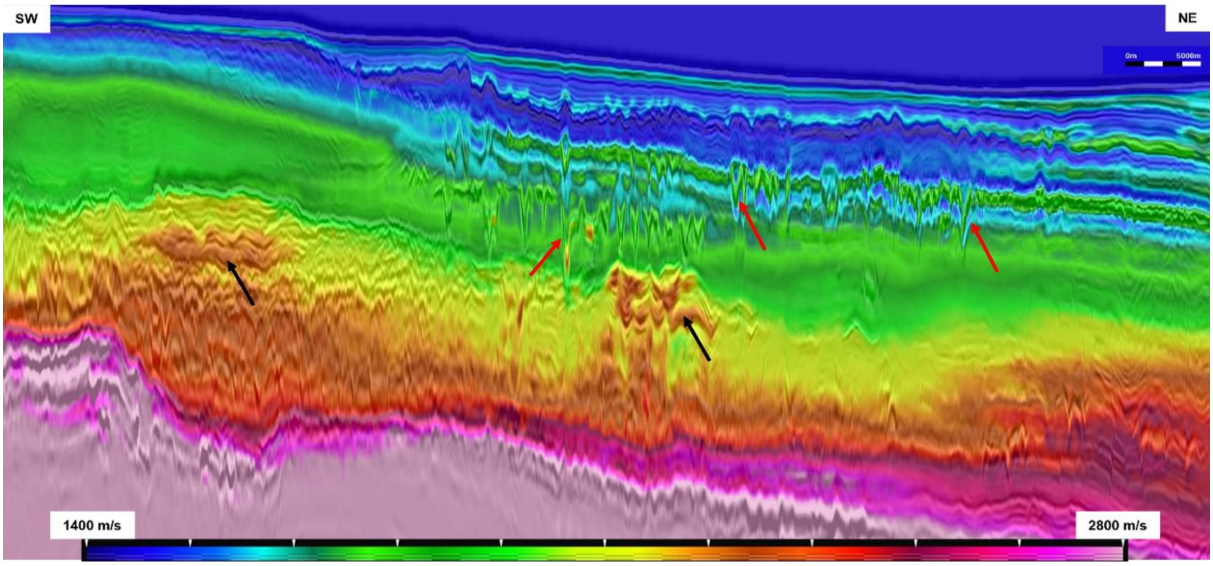

Figure 3 *Beam PSDM stack co-rendered with the final FWI model. Note the resolution of the injectites (red arrows) and the Eocene Fan deposits (black arrows) in the overburden.*

Once in place, picking the geobody volume was a quick process. The geobodies were derived on a conditioned Beam PSDM stack, using instantaneous amplitudes referenced to seismic responses at well locations. The geobody volume was subsequently sculpted to exclude unrelated responses in the shallow overburden and deep sections. This robust workflow allowed us to accurately identify the strongly varying extrusive and intrusive volcanic velocities, and to avoid the bleeding of those velocities within the background model. The subsequent series of geologically constrained reflection tomography updates has targeted the intra-volcanic reservoir velocity model and is characterized by sharp velocity variations; the results are shown in Figure 4.

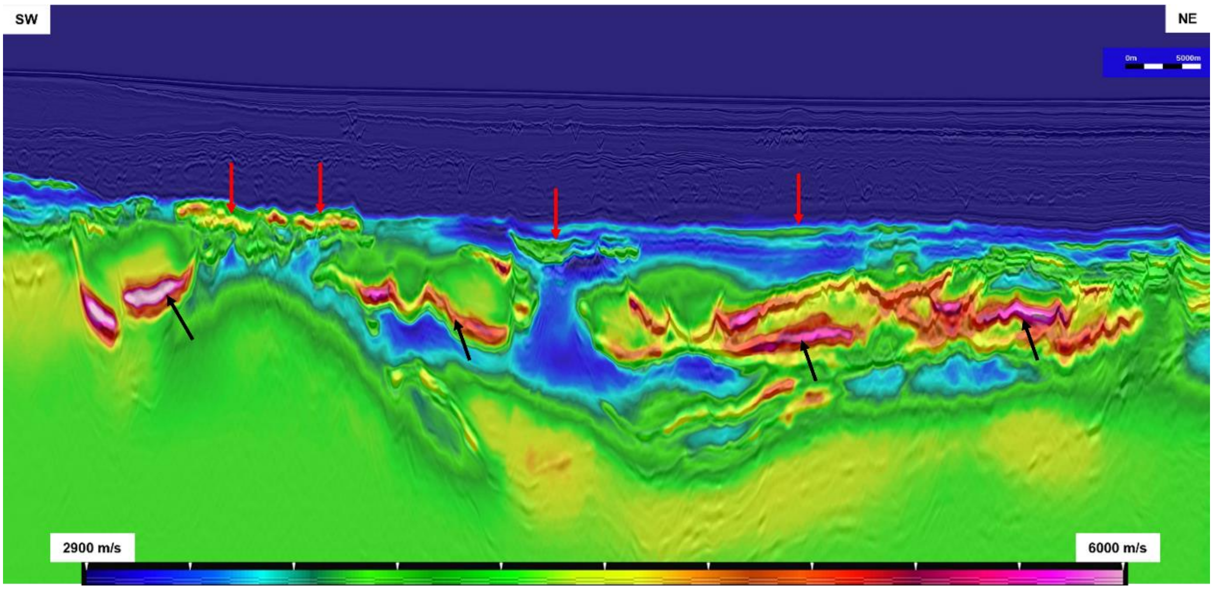

Figure 4 *The intra-volcanics velocity model has accurately resolved both the intrusive (black arrows) and extrusive (red arrows) volcanics within a very complex background model.*

Conclusions

We have presented a robust velocity model building workflow that leverages FWI updates and geologically constrained reflection tomography. It has allowed us to resolve the sharp lateral and vertical velocity variations in the overburden and to define sharp contrast geobodies to enhance the imaging quality of the intra-volcanic and intrusives associated targets. We demonstrate that applying advanced processing solutions to several vintages data can result in highly detailed and accurate models that are consistent and across the full area.

References

Brandsberg-Dahl, S., Chemingui, N., Valenciano, A.A., Ramos-Martinez, J. and Qui, L. [2017] FWI for model updates in large-contrast media. *The Leading Edge*, **36**(1), 81-87.

Ramos-Martinez, J., Crawley, S., Zou, Z., Valenciano, A.A., Qui, L. and Chemingui, N. [2016] A robust gradient for long wavelength FWI updates. *78th EAGE Conference and Exhibition, Extended Abstracts*, Th SRS2 03.

Smallwood, J.R., Prescott, D. & Kirk, W. [2004] Alternatives in Paleocene exploration west of Shetland: a case study. *Scottish Journal of Geology*, **40**, 131–143.

Smallwood, J.R.J. & Kirk, W.J. [2005] Paleocene exploration in the Faroe– Shetland Channel: Disappointments and discoveries. *In: Doré, A.G. & Vining, B.A. (eds) Petroleum Geology: North-West Europe and Global Perspectives: Proceedings of the 6th Petroleum Geology Conference. Geological Society, London*, 977–991.

White, N. & Lovell, B. [1997] Measuring the pulse of a plume with the sedimentary record. *Nature*, **387**, 888–891