Full-wave long offset seismic imaging and velocity analysis with gravity and well constraints – a case study from NW Corrib, offshore Ireland
Alexander Droujinine*, British Geological Survey, Steve Buckner and Ross Cameron, Marathon Oil Company

Summary
Long offset data from a recent marine streamer survey acquired in the Slyne Basin (NW Corrib, offshore Ireland) were reprocessed using advanced data pre-processing (source deconvolution, complex multiple attenuation and Radon-based wavefield separation), anisotropic velocity analysis and prestack time/depth full-wave imaging algorithms. Results of velocity analysis were constrained by borehole and gravity data to assist in the validation of interpretations. The focusing capabilities of symmetric wave modes have been analyzed and compared. Methods were incorporated into a single workflow tailored to identify key horizons below the top-basalt boundary.

Introduction
A high impedance contrast between the top-basalt (TB), base-basalt (BB) boundaries and the surrounding sediments is known to generate strong multiples and reduces the P-wave penetration (Purnell, 1992). This is proving to be a major problem for seismic imaging in the North Atlantic margin, from Norway to Ireland. The purpose of this case study is to demonstrate that full-wave decoupled imaging (Druzhinin, 2003) combined with the special data pre-processing sequence (Druzhinin et al., 2004) may be promising for delineating complex basalt lava flows and identifying weak sub-basalt reflections. To minimize velocity uncertainties, the calibrated logs, seismic data and non-seismic measurements such as high-resolution gravity data should be processed together. The aim of this study is to show how this integrated approach can be applied to long offset marine streamer data from NW Corrib, offshore Ireland (Figure 1). The A1483 data set was acquired by Veritas DGC Ltd. in 2002 using airguns (4450 cu. in., 2000 psi) as the source and the 8×6 km hydrophone cables for receivers. Other acquisition parameters are as follows: trace length is 7 s, sample rate is 4 ms, source depth is 12 m, source separation is 50 m, SP interval is 25 m, and minimum offset is 240 m.

Figure 1: NW Corrib data set: (a) location map with bathymetry and (b) 3D survey geometry.

Figure 2: NMO QC stack after noise suppression done by CGG (deterministic zero phasing using the far-field source signature in Figure 3, refracted multiple removal, DIMAT, high resolution Radon, K filtering, etc.).

Figure 3: Far-field source signature before de-bubbling.

Figure 4: Example of NMO semblance panel (a) before and (b) after source deconvolution.
Constrained full-wave long offset seismic imaging and velocity analysis

Figure 5: A portion of depth migrated section (a) before and (b) after SRME applied to prestack data.

Data Pre-Processing

After data QC (Figure 2) it was noticed that input traces showed some remaining noise due to source signature, inter-basalt multiples and PS waves due to P-to-S conversion at the TB boundary. To eliminate this noise, the following data pre-processing sequence was applied (Druzhinin et al., 2004): (1) source deconvolution using the far-field source signature (Figure 3) convolved with debubbling and receiver ghost filters, (2) QC test of “predict then subtract” prestack multiple attenuation algorithms such as the SRME (Verschuur and Berkhout, 1997), and (3) Radon-type wavefield separation and signal enhancement (Spitzer et al., 2003). Figures 4a and 4b illustrate the difference between including or omitting prestack source deconvolution. The method effectively attenuated some noise due to source footprint and rendered reflection events more coherent. Figure 5 demonstrates the impact of SRME multiple attenuation, revealing no significant effect on the coherent signal. This QC test proves the success of de-multiple done by the contractor.

Figure 6: Example of stacked sections after zero-offset time-to-depth mapping: (a) PP and (b) converted wavefields after GRT prestack wavefield separation.

Figure 7: Initial 3D interval P-wave velocity grid in time consistent with interpreted key horizons and sonic logs.

Velocity Analysis

The first step of the velocity model building is to apply the conventional Dix inversion to the stacking velocity field. Due to well-known uncertainties of Dix inversion, we focused our attention on a good match with interpreted time horizons provided by the contractor and interval velocities derived from calibrated sonic logs (Figure 6). In Figure 6, we choose to describe the interval velocity in each layer as a linear vertical gradient, unique for a single layer but different in each layer. Using the density-velocity relationship derived from log data, the velocity grid in Figure 6 was transformed into the corresponding density grid. This enables us to apply forward 3D gravity modeling (step 2). In the present study, the predicted gravity field...
Constrained full-wave long offset seismic imaging and velocity analysis

Figure 8: 3D gravity data processed by Ark Geophysics Ltd. for Shell E&P Ireland Ltd.: free air and Bouguer unfiltered gravity anomalies (in mGal) merged with the 3D bathymetry data.

Figure 9: (a) P/S velocity ratio $\gamma = V_p / V_S$ and (b) S-wave anisotropy coefficient $\nu = V_S(\text{slow}) / V_S(\text{fast})$ versus $V_p$ cross-plots derived from well log data.

Figure 10: Fragment of PP depth migrated section using (a) isotropic ($\eta = 0$) and (b) anisotropic ($0 < \eta < 0.1$) input velocities.

9a). The third step is to determine the anisotropy parameters by integrating well data and seismic data. The dipole shear sonic imager was used to obtain the fast and slow slowness logs below the BB boundary (Figure 9b). Using these logs, we estimate the average anisotropy coefficient $\nu = 1.05 \pm 0.02$. The Thomsen’s effective anisotropy parameter $\eta = (\epsilon - \delta)/(1 + 2\delta)$ was estimated by applying one of published long offset NMO corrections to CDP gathers. In Figure 10b, including NMO based anisotropy ($\eta = 0.05 \pm 0.025$) in the velocity produced migrated events with slightly more stable amplitudes around the BB boundary than those in Figure 10a. Finally, discrepancies between RMS velocities derived from surface and borehole data were incorporated into the 3D interval velocity model to account for remaining lateral velocity variations and/or intrinsic anisotropy.

Figure 11: Testing PreSTM of final moveout-corrected CDP gathers after data pre-processing (Figure 6a).
Imaging Results

Even though the application of PreSTM helped to improve the image of the BB horizon (Figures 11 and 12), most sub-volcanic units could not be seen on the migrated gathers indicating that imaging problems still exist. Therefore, we run trial time migrations of moveout-corrected CDP gathers over a range of anisotropy parameters to confirm that the final velocity model was optimal. The latter was then used in PreSDM of the surface seismic data from various lines (Figure 13). Each line was migrated several times, using the full-wave decoupled PreSDM formula (Druzhinin, 2003) that honors elastic imaging conditions and minimizes cross-talk between various wave types. Input data were preprocessed shot gathers after GRT wavefield separation. Figure 13 shows great improvement in image quality below the BB horizon over the original stacked data in Figure 2.

Figure 12: Result of PreSTM: 3D geometry of the interpreted BB time horizon.

Figure 13: (a) PP and (b) PSPSSP decoupled PreSDM of preprocessed shot gathers after GRT. Anisotropy is included into the velocity model.

Conclusions

The present case study has shown that full-wave imaging combined with prestack Radon wavefield separation after source deconvolution and complex multiple attenuation is suitable for sub-basalt imaging in the North Atlantic margin. The working assumption is that borehole and 3D gravity measurements are available for iterative model verification and refinement. A clear understanding of geological setting is also important in order to constrain the velocity picking.

Acknowledgments

This work was funded by the Edinburgh Anisotropy Project (EAP) at the British Geological Survey (BGS/NERC); it is published with the permission of Corrib partners (Shell E&P, Statoil and Marathon) and the Executive Director of the BGS. We are grateful to Xiang-Yang Li (BGS) for encouraging us to pursue this research. We thank Brian Bainbridge (BGS) for his work on maintenance of hardware and system software.

References