MULTI-WAVE-TYPE SUB-BASALT IMAGING

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Abstract

Well-guided multi-wave-type decoupled imaging of conventional and long-offset marine streamer data after Radon pre-processing has strong potential for imaging basalt layers and sub-basalt targets. Here, we discuss applications of this technique to two data sets recorded in the North Atlantic margin.

Introduction

A high impedance contrast between sediments and volcanic units is proving to be a major problem for seismic imaging in the North Atlantic margin, from Norway to Ireland. Multi-wave-type decoupled imaging (Druzhinin, 2004) combined with the Radon-type wavefield separation (Spitzer et al., 2003) has been demonstrated to be promising for delineating complex basalt lava flows and identifying weak sub-basalt reflections. To circumvent difficulties of accurate velocity estimates typical for model-based multi-wave-type imaging, a joint interpretation of seismic records, well data and non-seismic measurements is required. The purpose of this paper is to show how this integrated approach can be applied to marine streamer data acquired over a number of challenging targets. Two complementary case examples from the North Atlantic margin (UK and Ireland) illustrate the improvements in imaging through high-velocity layers using the standard acquisition of marine seismic data (example 1) and the advanced acquisition of larger offsets with low-frequency source (example 2).

Methodology

In principle, various wave modes (PP, converted waves, multiples, etc.) can be separated in the linear, parabolic or generalized Radon domain because of their different moveout parameters. These wave modes can be enhanced and properly migrated using the decoupled (either time or depth domain) imaging scheme (Druzhinin, 2004). To minimize velocity uncertainties, the calibrated logs, seismic data and non-seismic measurements such as high-resolution gravity data should be processed together.

Case Example 1 – North of Shetland (UK)

The single 2D seismic profile GWS94 was recorded in the North of Shetland (UK) in 1994. The objective was to study the internal structure of the Erlend Volcano.

Figure 1: Location map of the GWS94 target (arrow indicates well 209/9-1 at 61° 45' N, 0° 20’ W).

Figure 2: Calibrated sonic log furnished with a lithology and stratigraphy (well 209/9-1 owned by BP).
Seismic data were deconvolved and multiple reflections associated with the water bottom were removed (courtesy of Norsk Hydro). Log data (Figure 2) were used to constrain the velocity analysis. The migrated time section in Figure 3a has typical problems in basalt-covered areas: weak sub-basalt PP reflections and strong coherent noise (arrows indicate multiples). Owing to the large impedance contrast confirmed by log data, mode conversions at basalt layers are significant. Firstly, the focus was on the asymmetric wave mode PPSP to recover the basalt structure between the top and base (TB and BB) of the 400 m thick sequences of subaerial facies basaltic lavas (Figure 3b). Here, PPSP means downgoing P wave and upgoing S wave with conversion to P wave at the sea floor (SF). An improved velocity model was then constructed using the image of basalt layers in Figure 3b. Next, the new velocity model was used to isolate and migrate symmetric PP and PSPPSP (S traveling inside basalts) wave modes based on the decoupled PSDM workflow. This yields an accurate image of Cretaceous sediments (Figure 4).

Figure 3: Multi-wave-type processing of the GWS94 data set: (a) PP and (b) PPSP Radon enhancement of basalt reflections.

Figure 4: Well-driven shot-profile decoupled PSDM applied to the GWS94 data set (CDP 992-4140): velocity model was derived from log data (Figure 2) and SF, TB, and BB horizon picks (Figure 3b).
Case Example 2 – NW Corrib (Offshore West of Ireland)

Example 2 demonstrates the possible improvements in resolution that we can expect by merging Radon with time/depth processing. Seismic and gravity data in this study were acquired in the area adjacent to the Corrib Field located in the Slyne Basin, offshore the west coast of the Republic of Ireland (Dancer, 2002). Figure 5 shows the location map and the target block \( \Omega \) used in this study. Borehole data from the Corrib Field were processed to produce the density-velocity relationship and to construct the initial velocity/density model (Figures 6 and 7). 3D lateral velocity variations were constrained by gravity anomalies (Figure 8). Detailed 3D maps of TB and BB horizons were also made available (Figure 9). This enables us to generate a sufficiently accurate initial model by incorporating all *a priori* information about the basalt structure.

![Figure 5](image_url)

*Figure 5: NW Corrib data set: (a) location map and (b) survey geometry (target block \( \Omega \) is enclosed by the rectangle).*

![Figure 6](image_url)

*Figure 6: Well log P velocity-density cross-plots.*

![Figure 7](image_url)

*Figure 7: Initial P velocities derived from ZO VSP traveltimes and calibrated sonic logs. 3D lateral velocity variations are made consistent with gravity data (Figure 8) and horizon maps in Figure 9.*

![Figure 8](image_url)

*Figure 8: 3D gravity data processed by Ark Geophysics Ltd. for Shell E&P Ireland Ltd.: free air and Bouguer unfiltered gravity anomalies merged with the 3D bathymetry data.*
Figure 9: 3D geometry of volcanic units: TB (left panel) and BB (right panel) PP time horizon maps.

Figure 10 compares PP and converted-wave (Radon time and time-to-depth) processing results for the block $\Omega$. Compared with the PP image (Figure 10a), the converted-wave image in Figure 10b offers a good compromise result: the noise level is reduced and sub-basalt reflectors are better resolved than those in Figure 10a.

Conclusions

Our case studies have shown that decoupled imaging combined with Radon pre-processing is suitable for sub-basalt imaging in The North Atlantic margin. The common assumption is made that a priori information is available to generate sufficiently accurate velocity estimates.

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Figure 10: Multi-wave-type Radon-based processing of the NW Corrib data set (block $\Omega$): (a) PP and (b) converted wavefields.

References