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Imaging beneath Basalts in the Norwegian Sea Using RTM Tomography and Least Squares RTM

S. Baldock[1]*, T. Kim[1], T. Feng[1], Z. Guo[1], C. Zeng[1], H. Bondeson[1], B. Kjølhamar[1], M. Hart[1]

[1]TGS

Summary

Sedimentary basins with prospectivity potential beneath volcanic intrusions occur in many parts of the world. However, the rugosity and high-impedance contrast of the basalt create significant challenges in imaging sub-basalt structures. Two-way wave equation techniques may be employed to address the complex multipathing that occurs during propagation of the wavefield through basalt. This is illustrated by the successful application of common offset RTM (COR) tomography and least squares RTM to a 3D data set from northwest Europe. The use of these techniques has improved the imaging and the velocity model within and beneath the basalt.

Introduction

The rugosity and high impedance contrast of basalt, coupled with extreme heterogeneity in its internal structure, results in scattering of high-frequencies. The low-frequency energy that does penetrate the basalt is overprinted by high energy peg-leg and interbed multiple trains. Furthermore, sub-basalt reflectors are weak and easily obscured by strong noise or multiples (Spjuth et al. 2012). While Kirchhoff methods have been used to image beneath basalt, the complexity of the wavefield requires wave-equation solutions. We demonstrate the successful application of reverse time migration (RTM) methods, to the velocity model building together with more recent least squares RTM (LS RTM) imaging.

Method

The Møre Marginal High extends in a north-easterly trend from the UK border north of the Brendan Basin to the Jan Mayen lineament. It is defined by a 150-km long row of untested structural highs. The highs are untested due to an overlying volcanoclastic delta. To ensure the sediments beneath the basalt are successfully imaged, a 625 km^2 portion of data from a larger 45,000 km^2 survey, is processed with the specific intention of evaluating RTM-based techniques for sub-basalt model building and imaging. The flow has four main elements: 1) a reflection tomography for the supra-basalt sediments; 2) intra- and sub- basalt tomography using common offset RTM (COR) gathers; 3) post-RTM image enhancement using directional imaging stacks (DIS) and 4) least squares RTM.

The accuracy of tomography updates depends on the quality of the residual moveout (RMO) picking, which in turn depends on the signal-to-noise ratio of the gathers. If the signal-to-noise ratio is good, tomography using KPSDM can produce a high-resolution velocity model. However, below basalt, the signal-to-noise ratio of KPSDM gathers is low due to poor ray coverage and the small sub-basalt sediment reflectivity. Common-offset RTM (COR) gathers (Rodriguez et al. 2016), have a higher signal-to-noise ratio and more coherent events and can be used as input to a tomography update. For final imaging a data domain least squares solution was used – adaptive least squares RTM (Zeng et al. 2015) – which, improves signal-to-noise by suppressing migration artefacts and broadens the bandwidth of the data.

Results

Results are shown in Figure 3; 3a shows the Kirchhoff prestack time migration (KPSTM) stretched to depth. Some sub-basalt reflectors can be identified where the basalt is thick, but the reflectors are noisy and overprinted with swing noise. As the basalt thins the KPSTM image breaks down. Figure 3b shows the Kirchhoff prestack depth migration (KPSDM) result. Sub-basalt event continuity is improved with clear improvement beneath the thinner basalts. LS RTM (Figure 3c) reduces artefacts and improves continuity. Figure 4a shows the final velocity model overlaid on the final LS RTM. Velocity variation beneath the basalt related to fault blocks is picked out by the COR tomography. Figure 4b shows a 3D cut out view of the velocity model, values expected for sedimentary rocks occur in several locations beneath the basalt.

Conclusions

We demonstrate that the application of RTM based technology has improved the sub-basalt image and the velocity attribute. The seismic data shows recognizable sub-basalt events that can be picked across faults. The faults themselves can be picked with acceptable confidence. Sub-basalt velocities from COR tomography provide valuable interpretation support.

Although the methodology is successful, there is more that can be done to improve the image. Interbed multiples are not explicitly addressed, while techniques such as full waveform inversion (FWI) are expected to provide further uplift. These techniques will form the basis of further work.

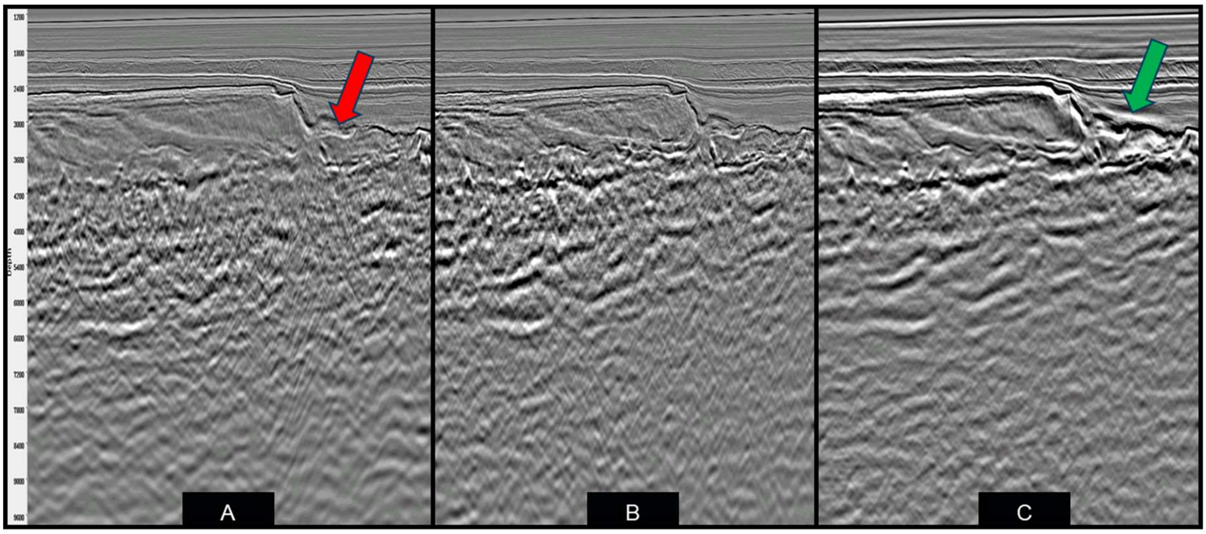

Figure 3 *Imaging and model building results: a) KPSTM converted to depth; b) KPSDM using the velocity model derived from COR tomography; c) LS RTM using the same model as b).*

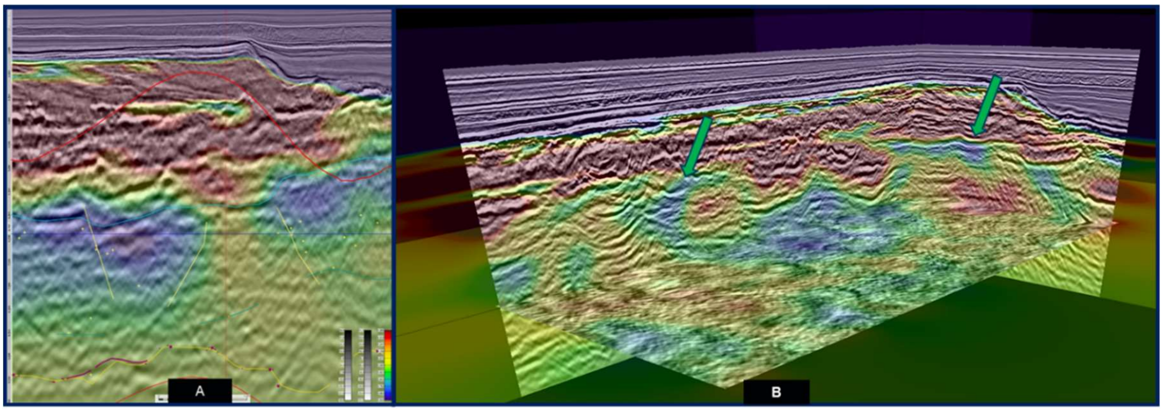

Figure 4 *Final velocity models: a) Inline view of final velocity model overlaid on the LS RTM image; b) 3D image of the same.*

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