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Improved Sub-basalt Structural Imaging in the Faroe-Shetland Basin Using Full Sequence Migration Multi-velocity Analysis

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SUMMARY

It is widely accepted that the key to successful sub-basalt imaging in the Atlantic Margin region is to generate as much low frequency energy as possible. Whilst recent acquisition in the Faroe-Shetland Basin (FSB) has seen the towing of sources and streamers at increasing depth to concentrate more energy into the low end of the amplitude spectrum, a large volume of data exists with a more conventional and shallower towed configuration such as TGS s FSB 1999 and 2000 surveys. Through the reprocessing of these datasets we demonstrate that a significant improvement can be made to image potentially prospective Mesozoic and Palaeozoic sub-basalt structures. This is achieved without compromising the relatively high resolution of the overlying Tertiary section.

We describe three key processing approaches which in combination are seen to provide a dramatic uplift over the original time processing. These are the enhancement of available low frequencies through a propriety spectral manipulation technique, multi-domain noise attenuation and a method we term Full Sequence Migration Multivel Analysis . The latter adopts strategies analogous to those used in pre-stack depth imaging and is seen to greatly enhance the interpretability of previously concealed structures at depth.

Introduction

In 1999 and 2000, TGS acquired 9779 km of multi-client long offset 2D seismic reflection and gravity data in the Faroe-Shetland Basin (FSB) (figure 1). Extensive thick sequences of basalt dominate the north-western flank of the basin. The main challenge to processing then, as it remains today, was imaging the prospective Palaeocene clastic sediments interbedded within basaltic flows and the potentially prospective Mesozoic and Palaeozoic section concealed beneath. Whilst the overlying Tertiary section was well imaged and the original dataset equally well received by exploration companies, it was proposed that the sub-basalt image could be improved by adopting recent processing strategies shown to be beneficial in the Atlantic Margin area and also through the introduction of less conventional approaches. Complete reprocessing of both FSB surveys was therefore undertaken in 2009 ahead of the UK 26th licensing round, incorporating several new strategies and ideas.

Here we describe three approaches which in combination demonstrate a dramatic improvement in the interpretability of the sub-basalt 2D time-domain image on a dataset acquired with conventional source and streamer tow depths, 7 and 9 metres respectively. These are the enhancement of recorded low frequencies through spectral manipulation, noise attenuation in several domains to maximize the signal-to-noise ratio and an interpretation-lead method we term Full Sequence Migration Multivel Analysis, adopting a strategy analogous to that used in pre-stack depth migration.

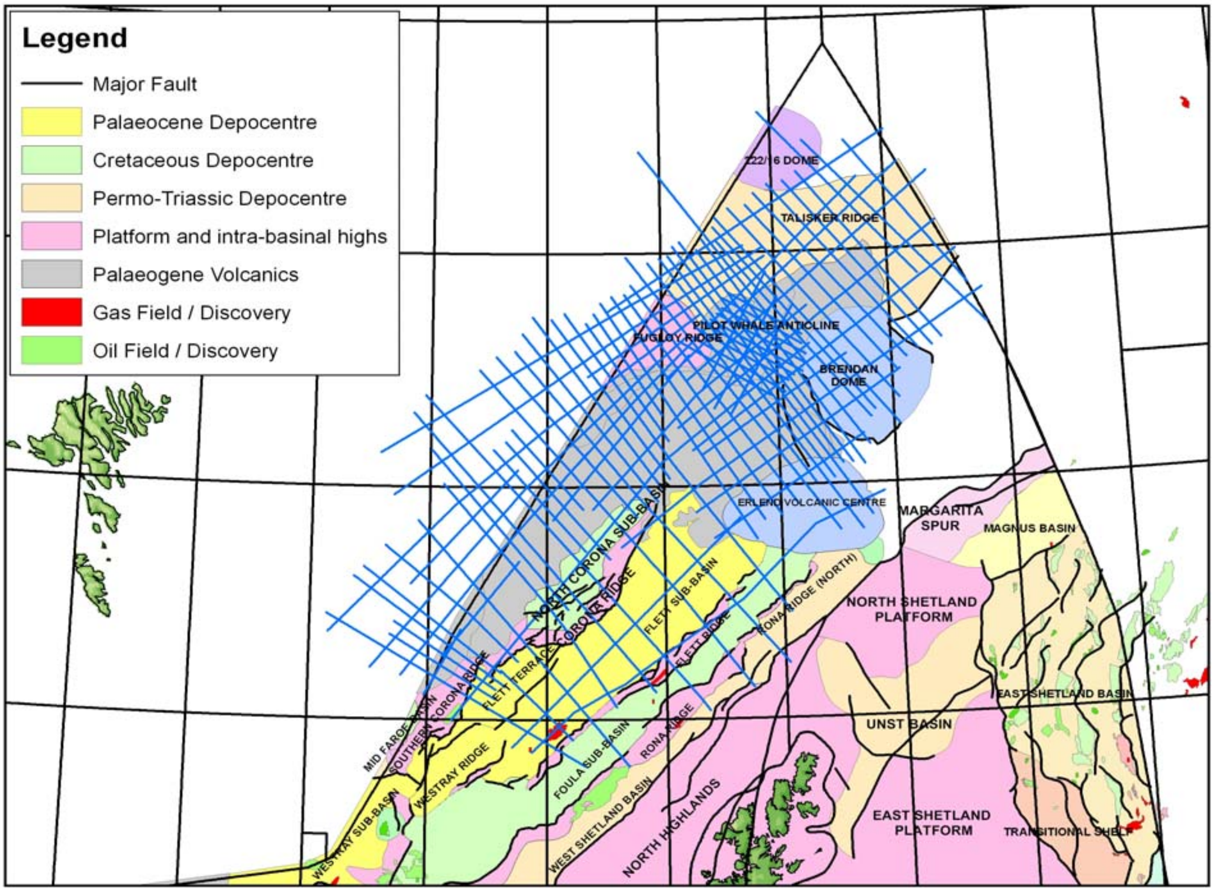

Figure 1 FSB 1999 and 2000 surveys. Basin bounding faults and major structural elements are shown in black. Palaeogene volcanics, where mapped, are shown in grey.

Problems of sub-basalt acquisition and processing

The vertical and lateral inhomogeneity of basalt flows in the FSB area results in loss of bandwidth as well as loss of signal. All but the lowest frequency seismic energy penetrating the basalt becomes incoherent either by anelastic attenuation which converts it to heat, or by elastic back-scattering. Scattering in particular poses a difficult problem due to the rugose top and base basalt and internal heterogeneity. Both give rise to complex multi-phase arrivals, significant multi-pathing and non-hyperbolic behaviour.

It is now accepted that the key to improved sub-basalt imaging is to generate and retain as much low frequency energy as possible (e.g. Ziolkowski et al., 2001). As a consequence, recent acquisition in the FSB area has seen the towing of cables and sources at increasing depths to concentrate more energy into the low frequency end of the source amplitude spectrum through constructive interference of the free surface ghost to image sub-basalt targets (e.g. White et al. 2002). Whilst accepting a deep towed streamer and source are beneficial, Gallagher and Dromgoole (2007) conclude that the sub-basalt image is primarily dependent on the processing sequence. From the reprocessing of vintage data with a shallow towed configuration similar to TGS's FSB 1999 and 2000 surveys a significant improvement to the sub-basalt image is made through the processing of low frequencies only, iterative velocity analysis and cascaded demultiple schemes.

TGS approach to sub-basalt imaging with vintage datasets: Data Preparation

Energy passing through the basalt is strongly attenuated at frequencies above ~ 30 Hz and to enhance available energy we apply a propriety method at an early stage of processing to statistically derive a wavelet representative of the de-bubbled and zero-phased source amplitude spectrum. We then manipulate the amplitude spectrum to generate a broader band response. An unsurprising effect is the boosting of swell and other acquisition-related low frequency noise as well as the low frequency signal. Rather than being counterproductive, this noise becomes easier to discriminate within the flattened primary amplitude spectrum. We apply multiple passes of frequency and threshold based noise attenuation in the shot, receiver, and CMP domains as well as standard F-X and F-K filters in the shot, receiver, CMP, common offset and stack domains to enhance weak low frequency sub-basalt primary energy and minimize both coherent and incoherent noise. Unlike deeply towed source and streamer configurations where high frequencies are lost due to destructive interference of the source and receiver ghost, the conventional cable tow-depth of 9m produces a notch in the recorded amplitude spectrum due to the receiver ghost centred at ~82Hz, and frequencies approaching this notch value are retained where useful to provide a high-resolution image of the overlying Tertiary section.

Full Sequence Migration Multivel Method

After spectral manipulation, noise attenuation and velocity-independent demultiple to remove surface-related multiples, we apply a time domain approach analogous to interpretation-driven subsalt Wave Equation Migration (WEM) scans in depth (Wang et al., 2006). At greater travel times and beneath the top basalt reflector, interpretation of seismic velocity based upon semblance maxima and gather flattening is problematic due to relatively weak primary returns and structural complexity. For this reason, an easier velocity analysis may be made by interpretation of stack images derived from stacking velocities based on a percentage of an approximate input function, commonly referred to as 'multivel' stacks.

Increased computing speed now allows the quick, full pre-stack Kirchhoff time migration of data to produce a suite of migrated images using migration velocities initially derived from selected percentages of the best set of stacking velocities. We term this Full Sequence Migration Multivel Analysis as these images have an almost complete pre-stack sequence applied and post-stack signal-to-noise enhancement to improve their interpretability. Velocity-based demultiple is performed immediately before migration to effectively remove residual multiple for each migrated velocity panel using the corresponding percentage velocity function. We generate a suite of up to 16 pre-stack migrated panels using Radon demultiple and migration velocities scaled typically within the range 60-140%, which are interpreted using the Multivel Picking Tool within TGS's PRIMA software. Picks on the migrated panels are related to gathers and semblances interactively. The data are then remigrated with the updated migration velocity field and further iterations performed if necessary.

Results

Figure 2 shows selected panels from the Full Sequence Migration Multivel Analysis across the northernmost part of the Corona Ridge and North Corona Sub-Basin. Ringed are examples of regions that give a preferred image, corresponding to analysis picks made. Figure 3 shows an example of the improvements obtained through reprocessing using this technique. This section crosses the Faroe-Shetland Escarpment where the Palaeogene flood basalts exceed thicknesses of 2 km.

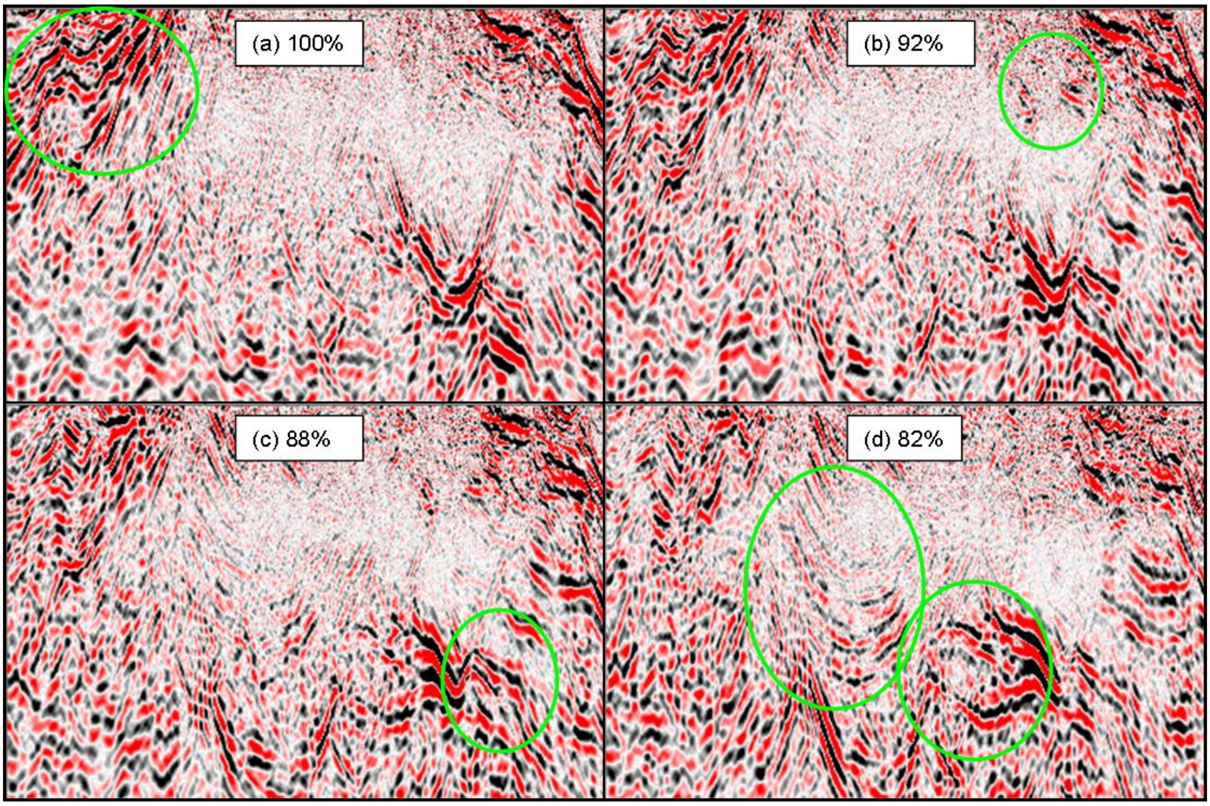

Figure 2 Zoom of selected Full Sequence Migration Multivel Analysis panels with the percentage velocity variation relative to the initial 100% function (a) annotated. Examples of preferred images are ringed.

Conclusions

We demonstrate a significant improvement in image quality through the reprocessing of our FSB surveys using the three key approaches outlined. Careful attention to the preservation and enhancement of low frequency signal and the attenuation of noise in multiple domains are seen to be crucial to improving signal-to-noise beneath the basalt. We show there is no need to compromise the frequency content of the overlying Tertiary section when reprocessing shallow towed datasets for sub-basalt targets. The third approach, Full Sequence Migration Velocity Analysis, is seen to be the key to improving the structural interpretability of concealed Mesozoic and Palaeozoic structures during the velocity analysis stage. This procedure can now be run within the time frame of a quick turnaround large scale production project. It permits the early involvement of interpreters, to whom the choice of a range of alternative structural images may be presented, each with the processing and signal-to-noise characteristics of a final section, and a 'composite' image built up from these. The final time domain migration velocity field should provide an excellent reference model for initial passes of pre-stack depth migration and tomography-based velocity updates.

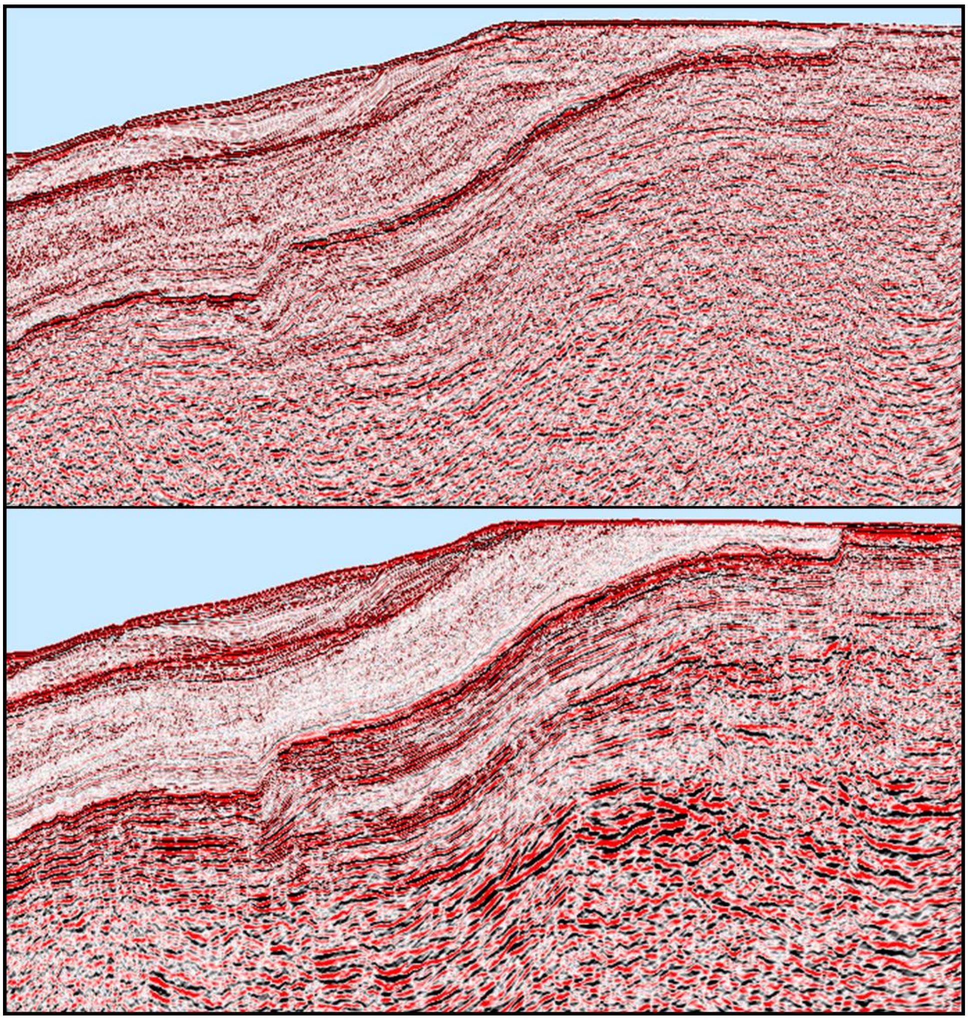

Figure 3 Final pre-stack time migrated image showing a comparison between the original processing (above) and 2009 reprocessing (below) across the Faroe-Shetland Escarpment.

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