Enhanced low frequency signal processing for sub-basalt imaging

Seismic imaging beneath basalt flows constitutes a significant challenge in many prospective basins around the world. These flows are often present as heterogeneous high-velocity layers of varying thickness.

Lower frequency energy in the source wavelet is more likely to penetrate through the basalt than higher frequencies as it is less attenuated by intrinsic absorption, and less scattered by the heterogeneity of the basalt reflectors. A solution to providing improved images beneath basalt flows is therefore to generate, retain and enhance as much low frequency energy as possible. Whilst accepting that carefully parameterised acquisition can be used to provide a greater richness in low frequency signal the sub-basalt image is primarily dependent on the careful retention and enhancement of low frequency signal at the seismic processing stage.

Here we present two key signal processing techniques which have resulted in the successful reprocessing of over 100,000km of long-offset 2D seismic data from across the northwest European Atlantic Margin and offshore Greenland where imaging beneath basalt is crucial.

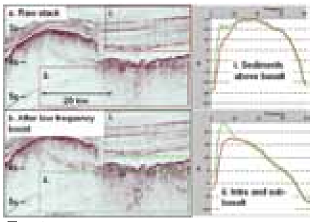

Fig 1

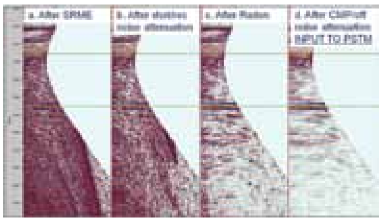

Fig 2

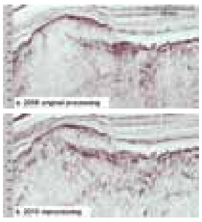

Fig 3

Signal processing: low frequency boost

At the beginning of data processing, after conversion to zero-phase, the recorded source wavelet is manipulated in order to enhance the signal at the low frequency end of the amplitude spectrum. The low frequency components of the wavelet are shaped to generate a target wavelet and appropriate zero-phase matching operators – one operator for each vintage of seismic acquisition. The operator provides a maximum boost in the 3-7Hz frequency band where signal levels drop off rapidly in the input spectrum. The operator also provides a smooth increase in the 7Hz to peak-frequency range to approximately simulate a deep towed source array. This apparent spectral shaping is in alignment with some key findings made in an evaluation on the spectral output of marine airgun arrays.

Boosting low frequency signal as part of post-stack spectral manipulation is a common process. Moving to a pre-stack application is important, and the decision to apply the boosting operator at the beginning of the data processing sequence is considered key for the following reasons:

Firstly, as the boosting operator does not discriminate between signal and noise, the poor signal-to-noise ratio found at low frequencies is not improved after the simple process of applying the operator. However, by applying the operator at the start of processing, the noise component assumes its true prominence relative to signal within the flattened amplitude spectrum. This in turn enables the full suite of signal enhancing components in the processing sequence to be tested for optimal application to the boosted low frequency data.

Secondly, seismic horizons related to the intra and sub-basalt geology are more easily identified in low frequency enhanced data displayed as stack images, gathers, and in semblance plots. In consequence, more accurate sub-basalt velocity models can be produced throughout the processing sequence. Since many pre-migration demultiple and noise attenuation processes are guided by the primary velocity function, these algorithms can be applied to greater effect.

Figure 1 displays the results of applying the low frequency operator to the 'raw' zero-phased data. The accompanying spectral analyses show the frequency content of tertiary sediments overlying the basalt are not compromised by this process. Furthermore, application of a single boosting operator does not affect the natural attenuation of higher frequencies through the basalt.

Multi-domain noise attenuation

Several noise attenuating processes were performed in all of the available 'time-offset' domains. Noise attenuation techniques were applied in the shot, receiver, common mid-point (CMP), and common offset domains to enhance low frequency sub-basalt primary signal, and minimise both coherent and incoherent noise. Techniques employed include:

- Coherent noise attenuation using a time and space variant f-x apparent velocity dip filter;
- several iterations of an algorithm which decomposes data into frequency bands and identifies and attenuates anomalous amplitudes within those bands based on time variant thresholds, and multiple passes of time and space variant f-x deconvolution – regularly operating only below the top or base basalt horizons

Figure 2 displays a sample NMO-corrected CMP gather after several key pre-migration processing stages. These data show the significant improvements made by the shot and receiver noise attenuation applied after SRME, and the subsequent improvements made by the CMP and offset noise attenuation after Radon demultiple.

Conclusions

We demonstrate significant improvements in imaging intra- and sub-basalt geology through the reprocessing of long offset 2D seismic from across the northwest European Atlantic Margin and offshore Greenland. An example reprocessed PSTM image is compared to the original 2008 processing in figure 3. Significant uplift to the intra and sub-basalt image is shown without compromising the broader spectral content of the overlying sediments. The two signal processing approaches key to providing these improvements are the application of a single low frequency boosting operator at the beginning of the processing sequence, and the application of several noise attenuation processes performed in the various 'time-offset' domains. ■

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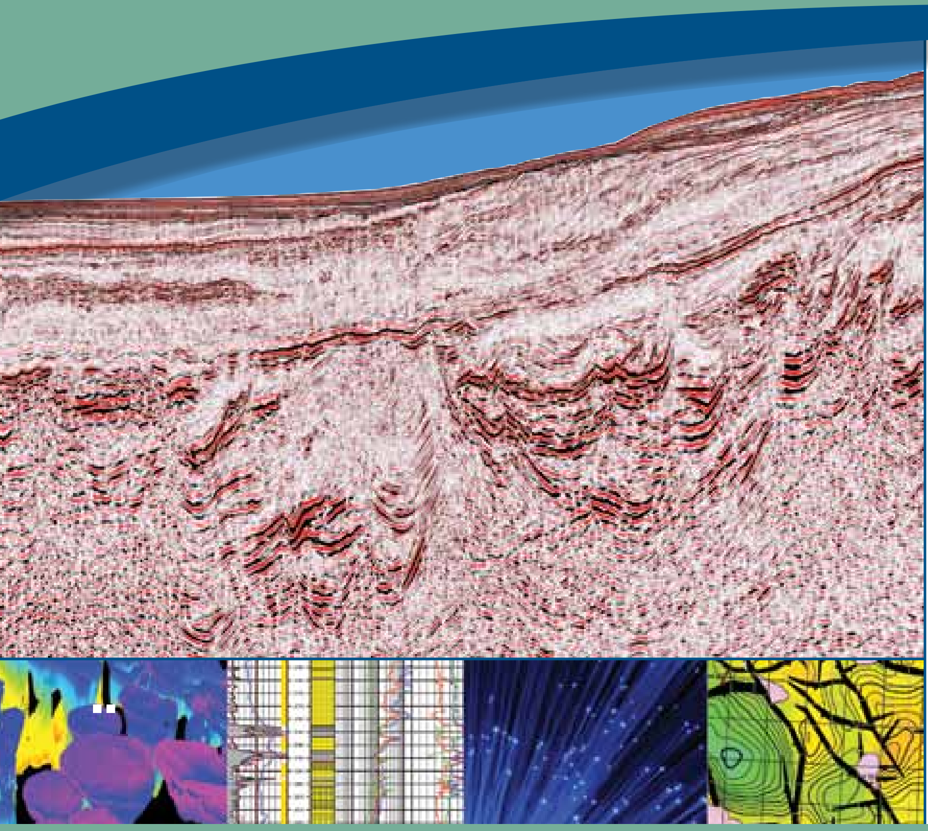

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