Progress in imaging through Basalt on the North West Frontier

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Summary
We describe a recently acquired multi-client survey over part of Hatton Bank and Basin some 750km west of Scotland. Figure 1 shows the location of the new and existing long offset lines. The area forms part of the Rockall plateau an area known to be underlain by continental crust. It includes a number of large central igneous complexes which have been mapped by the British Geological Survey (BGS) using seismic and potential field methods and sampled by shallow drilling (Hitchen, 2004). These centres have produced basaltic lavas covering most of the area but locally they are thin or absent and steeply dipping and folded sediments have been imaged in these areas using low fold short offset "high resolution" acquisition. BGS boreholes 99/1 and 99/2A located on Hatton Bank over the largest of the basalt "windows" sampled mid-cretaceous shales and sandstones close to the seabed. As the area is considered to have hydrocarbon potential (Gatliff *et al*., 2003) TGS carried out a regional survey in 2007 with the object of better imaging the Mesozoic sediments both within the windows and if possible beneath areas where the lavas are thicker.

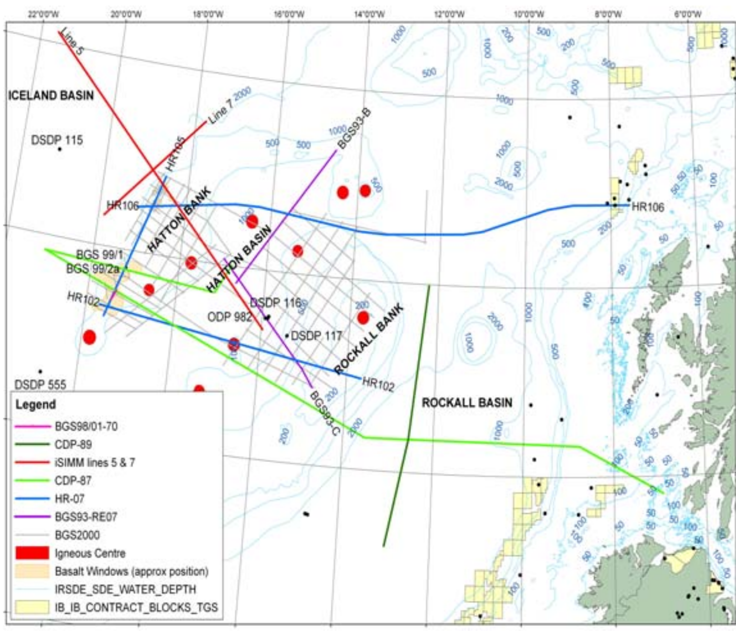

Figure 1. The TGS-NOPEC 2007 survey lines are in blue – total length 1230 km:
Shot by m/v Akademik Lazarev
4258 cu" air gun array @ 10m –25m SP
8100m cable @ 20 m-12.5m GI
Fold 162.

The BGS 1993 Rockall Margin transects B and C are in purple- total 408kms:
Shot by m/v Acadian Searcher
9390 cu" air gun array@10m-50m SP.
6000m cable @ 15m-25 m GI
Fold 60

Black dots show well locations including DSDP and ODP drilling sites.
Red dots show igneous centres
Fawn indicates known "basalt windows"
Grey lines are short offset survey shot by BGS in 2000

We discuss the nature of the imaging problem and the measures that can be taken in both acquisition and processing to overcome them. Then we describe a novel two stage wavelet processing strategy and show the improvement resulting from its use. Modern processing focused on low frequencies is shown to reveal interpretable sub-basalt structure and to significantly enhance the BGS data shot in the area in 1993.

Introduction

The difficulties of obtaining interpretable seismic images from beneath the thick basalt flows which cover large parts of the north west margin of the UK continental shelf are well known. They arise as a result of the presence of strong surface multiples generated by the reflective and rugose surface of the flows and strong interbed multiples generated within the highly layered lava sequence. Furthermore the heterogeneous nature of the flows results in loss of coherence in the higher frequency signal components. The average effective Q of a 1.7 km finely layered basalt sequence drilled beneath the Rockall Trough has been found to be only ~ 26. (Maresh *et al*., 2006) Energy passing through the basalt is observed to be strongly attenuated at frequencies above ~30 Hz.

Acquisition

Use of longer recording cables, yielding high fold CMP gathers and tighter stack response improves the low sub-basalt primary to residual multiple signal ratio but more powerful sources do not necessarily help as the multiple energy is source generated. Sub-basalt primary reflection energy may be differentiated from residual surface multiple "noise" by its narrow band low frequency content. Thus use of a source biased towards low frequencies increases the sub-basalt signal to multiple ratio significantly. This has led to the use of air gun arrays containing large volume guns designed to generate strong low frequency bubble pulse energy enhanced, through being towed deep, by the surface ghost effect. (Hobbs, 2002; Ziolkowski *et al*., 2003) Using a deeper than normal recording cable is beneficial for the same reason and has the added benefit of providing a quieter recording environment.

In preparation for the 2007 survey we modeled the signatures of the available gun array as a function of tow depth in order to optimize low frequency generation. We found that towing the source at 15m is predicted to produce a boost of ~10 dB relative to towing at 5 m for frequencies between 10 and 30 Hz. It would appear that the deeper the source the better. However the bubble pulse frequency increases and its spectral peak broadens with increased tow depth as seen in figure 2. This is because the bubble pulse frequency and its harmonics rise due to the higher ambient pressure at greater gun depth. For operational and safety reasons the maximum tow depth possible was only 10 m for the available vessel. While this compromised the output from 10-30 Hz relative to a 15m tow it should improve the performance below 8 Hz. The advantage of the deeper tow is modified slightly when the effect of the cable ghost and the attenuation of high frequencies by the basalt is modeled. The spectra shown are those of the predicted signatures after 1s of two way travel through basalt having an average Q of 30. This corresponds to passage through a 2 km thickness if the average velocity of the basalt were 4 km/s. The effect of recording by a cable towed at 20 m is included as can be seen in the spectral notch at 37.5 Hz.

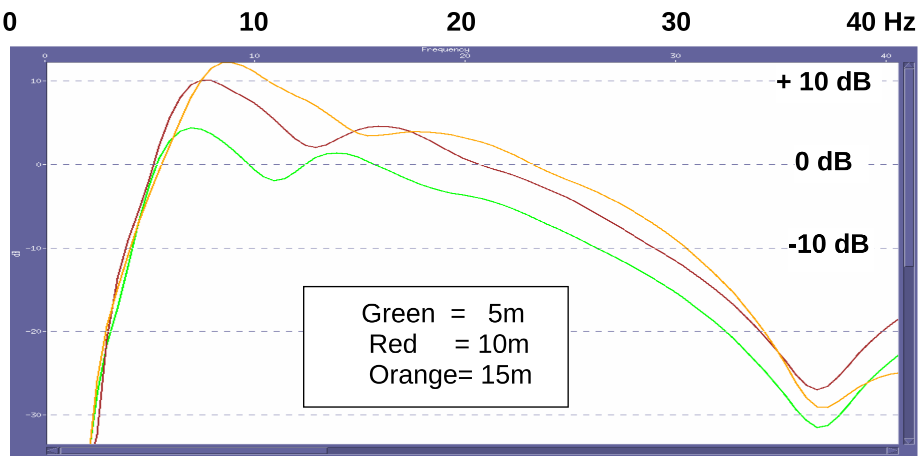

Figure 2. Power Spectra 4258 cu in source array with 20m cable ghost. High frequency loss was simulated using an effective Q of 30 for 1s twt through basalt. Note higher output below 8Hz of 10 m v 15m source depth

Cable depth of 20m was selected to enhance energy up to ~35 Hz.

Processing

Processing has to complement acquisition and ensure the enhanced low frequency is not irrecoverably lost. We present a strategy based on Hobbs & Martini (2002) in which we use a quasi-deterministic manipulation of the amplitude and phase spectra called 'SpecTwist'. It is a minimalist strategy requiring the fewest possible steps to achieve an acceptable result. It may not be theoretically the optimum solution but provides a robust image that is a benchmark for other processing strategies that aim to recover a low-frequency image. There are only two filters that manipulate the spectral content of the data and both of these are quasi-deterministic, i.e. they are time and space invariant but derived from the data.

The first filter, applied pre-stack, transforms an estimated de-ghosted source signature into a band-limited zero-phase target wavelet but does not attempt to de-ghost the data. The second filter applied post stack compensates for the average effect of the source and receiver surface ghosts. The rational for treating the source signature and the ghosts separately is that the source and its bubble pulse are reasonably constant throughout acquisition whereas the ghosts may be highly variable. Even with possible depth changes of +/-1 m (a typical quality control specification), the change in hydrostatic pressure does not cause a significant change in the shape of the all important bubble pulse. This is not true for the source and, especially, receiver ghosts in the large swells experienced on the northwest margin of Europe. As a result the location of the ghost notches may move significantly from shot to shot and from receiver to receiver. (Kragh *et al.*2004)

It is important that these filters are designed from the data as it is unlikely that idealised modeled source signatures will be sufficiently accurate. In 'SpecTwist' no attempt is made to compensate for Q, the quality factor, so the reflection image retains the frequency loss with travel-time effects as aids interpretation as reflections from beneath the basalt are only low-frequency whereas residual multiple energy from the supra-basalt structure will still retain a broader bandwidth.

After compressing the source wavelet the thrust of processing was to remove as much multiple energy as possible. A combination of SRME and radon based filters were applied in an iterative manner. Velocity sensitive multiple attenuation techniques such as parabolic radon filtering are only applied when sub-basalt energy is seen and its velocity picked with reasonable confidence. Figure 3 shows that the filter applied removes the bubble pulse coda forcing its energy into a zero phase wavelet. The latter had its spectrum restricted to of 2-4-44-62 Hz allowing subsequent re-sampling and processing at 8 ms. The resolution is much improved at all levels as a result. After a single pass of multiple suppression using SRME, weak sub-basalt reflectivity can be seen. Application of a de-ghost filter enhances this energy which can be clearly followed at ~ 4.8 s twt in fig 3(d). Given that the data has been stacked with brute velocities picked only every 20 km this was an encouraging early result. The timing and structure of the energy suggests that it is genuine primary energy though the presence of some residual multiple energy cannot be ruled out.

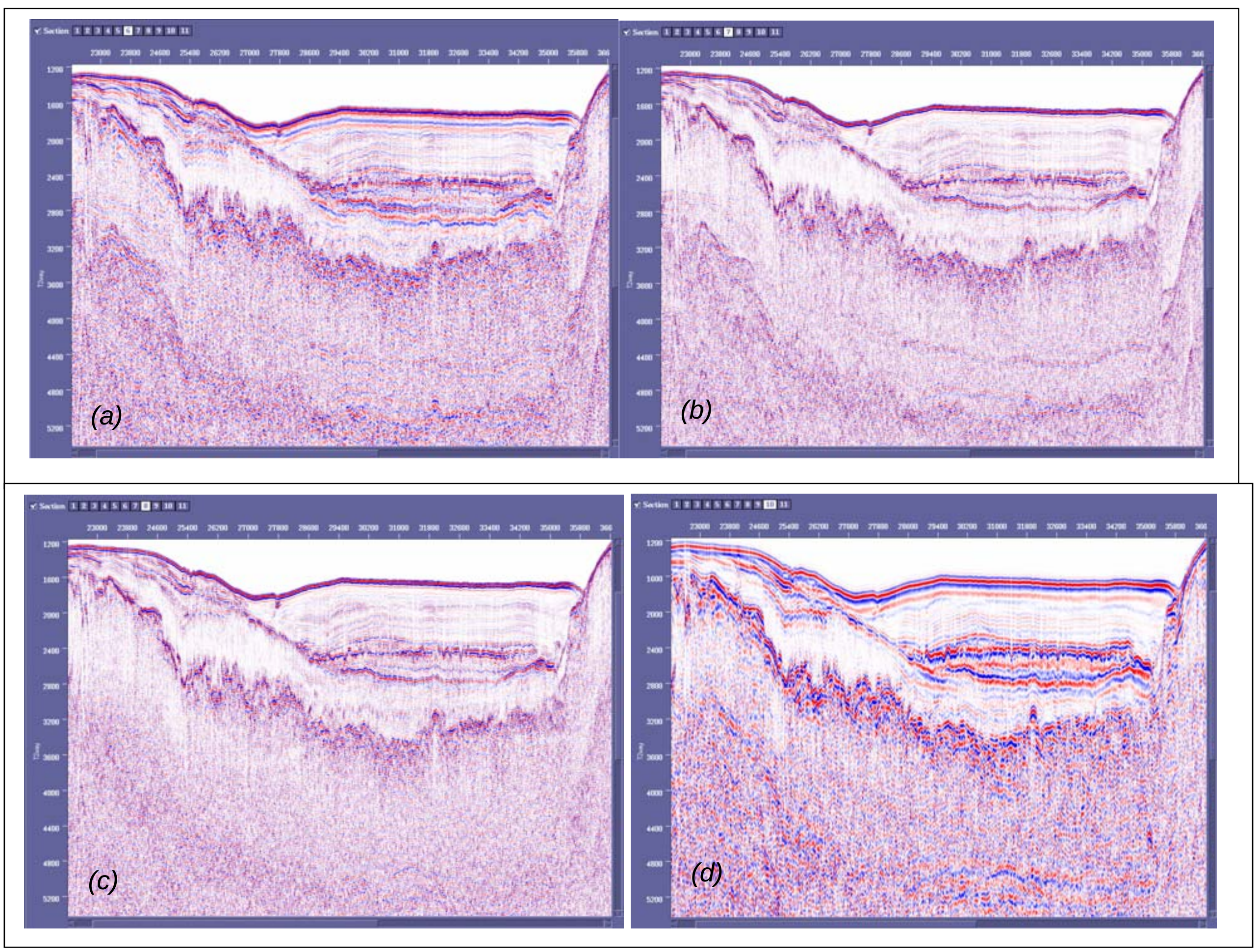

Figure 3. Part of HR102 (a) raw brute stack; (b) stack after application of first SpecTwist de-bubble filter; (c) as (b) with SRME applied; (d) stack after second SpecTwist de-ghosting filter.

Reprocessing of the BGS transect lines confirmed the presence of prominent low frequency sub-basalt reflectors throughout the Hatton Basin. Figure 4 compares the original migrated section with that re-processed in 2007. 'SpecTwist' was not used in producing this image.

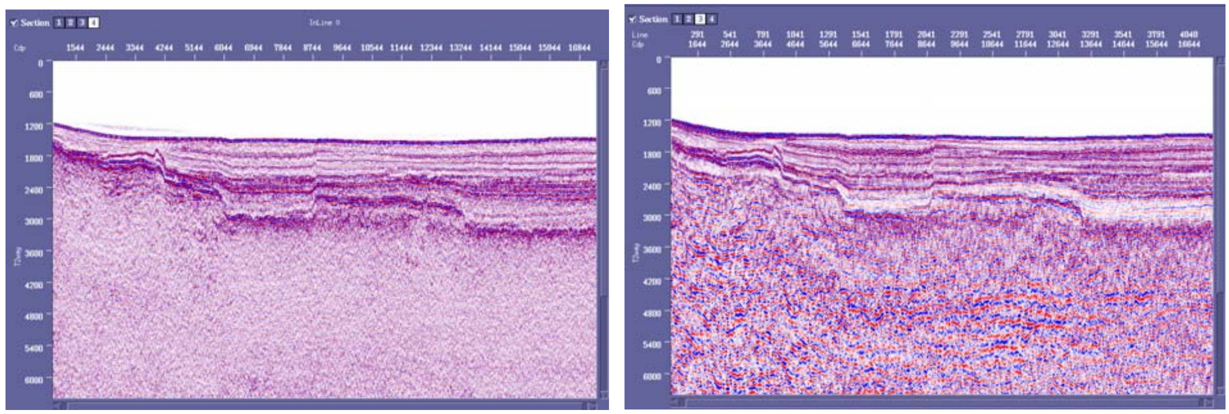

Figure 4 shows part of BGS Transect 93B
Original processing *re-processed 2007*

Figure 5 shows part of line HR105 shot over Hatton Bank very close to the area where BGS short offset data imaged the steeply dipping folded and faulted sediments sampled by boreholes 99/1 and 99/2A. The reflectors can be seen to dip to over 2s twt below the seabed considerably greater than the 300ms seen on the short offset high resolution data. This shows the power of modern long offset data to better image the Mesozoic sediments.

South West **North East**

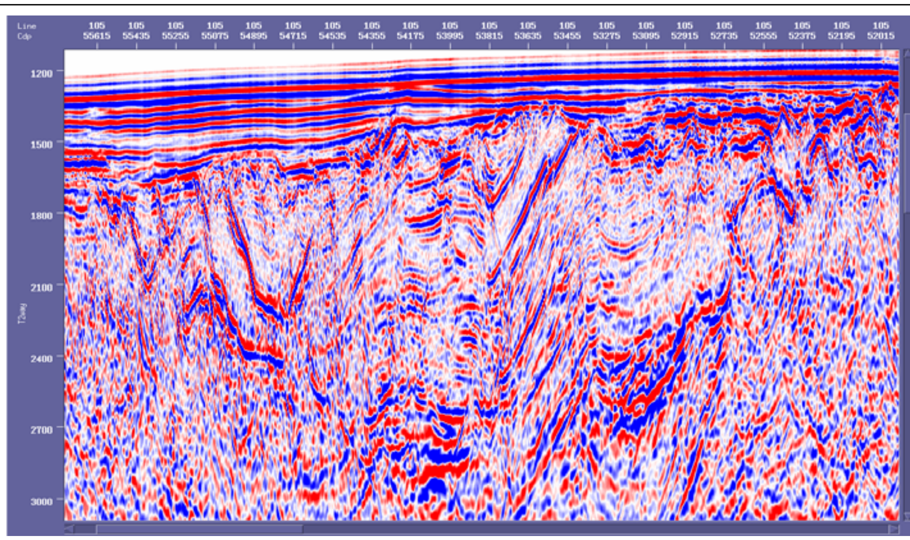

Figure 5 Part of Line HR 105 over the large basalt "window on Hatton Bank

Conclusion

We have demonstrated that modern acquisition using long cables and sources optimized for low frequency energy when linked to a processing strategy aimed at preserving these low frequencies can yield significant improvement in sub basalt image quality. Modern velocity independent multiple attenuation contributes to this as does careful iterative velocity picking followed by the noise reduction resulting from pre-stack migration. We consider that concentration early in processing on low frequency energy and the use of deterministic wavelet processing are key ingredients for future success.

Acknowedgements
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