Sub basalt imaging: A case study from Offshore India

Vikash Tripathi[1], Jun Zhou[1], S Chandrasekher[2], P Mishra[2], Rajesh Madan[2], M Maheshwari[2] Xuening Ma[1], Jeff Pidhirnyj[1], Gary Koo[1]

[1]TGS AP Imaging Services, Perth, Western Australia

[2]ONGCL, India

Abstract

To effectively delineate the deep Mesozoic structure beneath the thick Deccan basalts in the study area referred here has been a long challenging sub-basalt imaging problem in the industry. Significantly improved results have been achieved recently through mutual co-operation between ONGCL and TGS.

We present here a strategically designed effective processing work flow based on concurrent developments in seismic data processing techniques such as seismic data bandwidth broadening, accurate complex multiple removal and noise attenuation.

The successful application of this processing work flow has resulted in superior sub-basalt image which had never been seen in this basin.

Introduction

The study area is in shallow marine with WD < 30m, where long offset data (12km streamer length and streamer depth of 15m) was acquired and was processed earlier. The processed output showed hazy reflectors with poor S/N below basalt. Tertiary thickness above basalt is varying up to 3km and has a strong Late Oligocene level reflector. Eastern part of the survey area is clastic dominated with inter layering of limestone, while west is dominantly limestone. The existing well data suggest thickness of basalt up to 3km and presence of clastic within Mesozoic.

Recently, TGS was awarded a re-processing project for 2D long offset lines by ONGCL with the expectation to image the structure beneath the thick Deccan basalt by applying its Clari-Fi® Amplio® and other advanced processing technologies. The objective of the reprocessing project was to produce high resolution and reliable sub-basalt imaging.

However the data from the study area is exceptionally noisy due to shallow hard water bottom, shallow carbonate formation which generated complicated strong linear noise, strong reverberations and multiples. In addition to the above shallow water problems the thick Deccan basalt (several flow of lava, partly weathered which added to further attenuation) prevents the penetration of reflection energy which further degraded the data quality.

At each processing step detailed investigation/tests were carried out to devise and implement the best possible processing methodology to address the above challenges. The efforts were mainly made to focus on low frequency signal recovery/enhancing to retrieve deep reflection signals underneath basalt, complicated multiple removals and various multi domain noise attenuation to maximize S/N ratio.

The results obtained with the newly developed processing flow are very impressive. The new sub-basalt image has opened several possibilities in this region.

Challenges and solutions

One of the characters of the study area is that it is covered by a large area of thick Deccan basalt which is extremely heterogeneous and scatters the seismic energy of the conventional seismic reflection signal. As a result of the existence of the thick Deccan basalt it becomes extremely difficult to identify reflection signals from deep reflectors beneath the basalt. In addition to the problem due to the existence of the thick Deccan basalt the seismic data quality from this basin is further degraded by the character of hard shallow water bottom which together with the carbonate within the shallow tertiary formation forms a complex multiple generator system.

Since high frequencies are scattered/ attenuated more than low frequencies and the low frequency component is more critical in distinguishing a reflection boundary, a solution to enable the identification of the reflection signal from deep reflectors beneath the basalt is to enhance the low frequency components of the seismic signal. One possible technique is to employ or configure an acquisition system by increasing the volume of the air gun and the depth of the towed streamer. Unfortunately, the shallow water character of this basin declines this acquisition solution.

On the other hand the industry has witnessed the rapid development in broad band seismic exploration through seismic data processing based techniques in the past years. Clari-Fi® is TGS's proprietary processing based broad band seismic technique. Clari-Fi® Amplio® is a processing based broad band technique particularly designed to address low frequency boosting to address problems such as the sub-basalt imaging challenge where the high frequencies do not contribute to the signal very significantly and low frequency recovery is one of the critical points to the success.

It has been seen that the low frequency components are significantly boosted and the seismic signal are effectively enhanced after the application of Clari-Fi® Amplio®. Once the low frequency reflection signal was enhanced and noise successfully attenuated, the next challenge was the picking of accurate velocity and subsequent removal of multiples. The presence of very strong inter-bed multiples (particularly related to trap), with similar move-out as the primaries of sub-basalt posed the biggest challenge. The enhanced low frequency reflection signal makes the more accurate sub-basalt velocity analysis possible throughout the processing sequence. Accurate velocity analysis in turn results in better sub-basalt stacking responses of higher S/N ratio.

With reliable velocity analysis, the next step was to attenuate multiples from the data.

The large impedance contrasts associated with top, base and internal layering of the basalts, are generators of severe multiples. The inhomogeneity within the basalt layer, the sediment-basalt interface, further scatters the energy.

Therefore the most challenging task in the processing this data set was to attenuate the multiples without damaging primaries.

The water bottom of the project area is shallow within a range of 30-70 meters, the conventional SRME approach did not produce desired demultiple results in dealing the severe multiple problems associated with carbonate and basalt layers. A combination of HMT (H. Masoonzadeh et al, 2012) and SMELT (A. Hardwick, 2010) were tested and implemented in demultiple processing. High-resolution

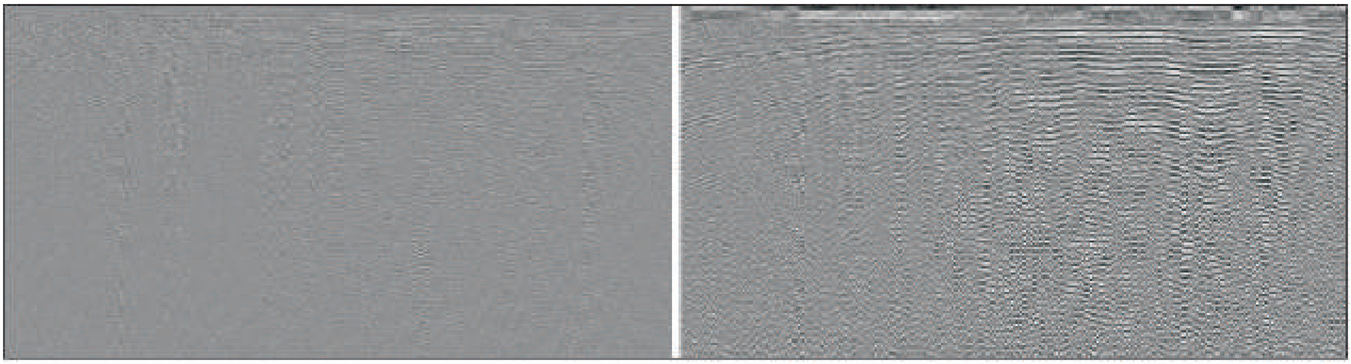

Fig. 1: NTG before and after low frequency boost

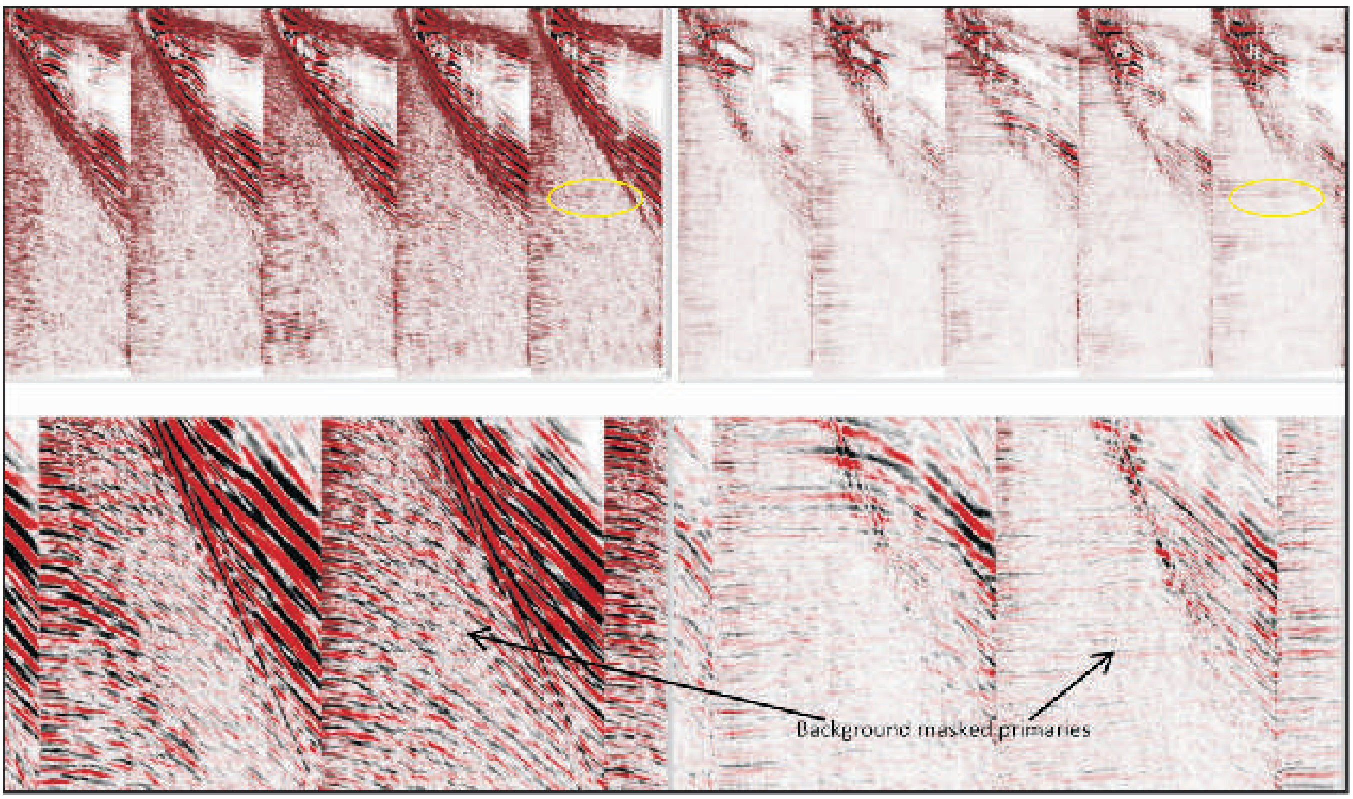

Fig.2: CDP gathers before and after HMT® (full and zoomed examples)

Moveout Transform (HMT®) is a method of transforming time domain gathers by iteratively searching for the optimal velocity range that produces maximum stacking energy, then removing the highest stackable energy in the transformed domain. The objective here is to find a number of optimized traces in the tau-pnmo domain to represent the energy of an input gather in the time-offset domain, where tau is the zero-offset two-way time and pnmo is the inverse of the velocity value being used to form a velocity function for NMO correction. HMT® has better resolution than high resolution Radon transform, it also improves multiple modelling in the near offset zone by reducing ambiguity in the data reconstruction at missing offsets.

Stepwise Multiple Elimination using Linear Transforms (SMELT®) was applied as a further de-multiple process after HMT®. By definition, SMELT is applied in a stepwise manner passing data through a series of linear transform pairs, related to a discrete velocity interval to build multiple models which are adaptively subtracted from the input at each step. The process is effective in attenuating a wide range of free surface multiples and significant internal multiples generated by shallow unconformities on the near to mid offsets of a CMP gather (A. J. Hardwick 2010).

Tau-P domain deconvolution was also applied to the data to attenuate short period reverberations from the data.

The third most important key step to the success of imaging was multi-domain noise attenuation at different stages. Several noise attenuating processes were performed in all of the available 'time-offset' domains. Noise attenuation techniques were applied in shot, receiver, common midpoint (CMP), and common offset domains to enhance low

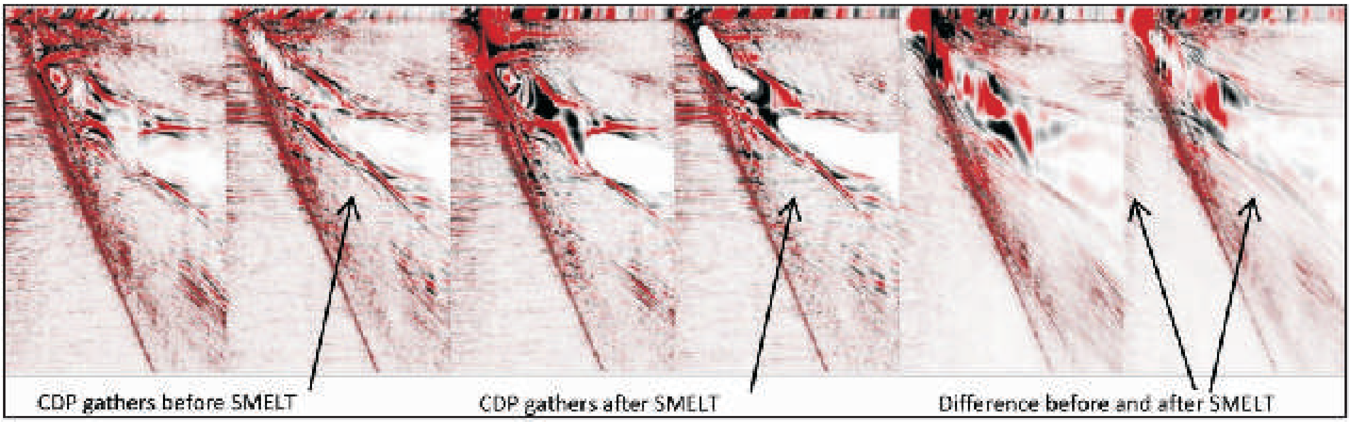

Fig. 3: CDP gathers before and after SMELT® and their difference

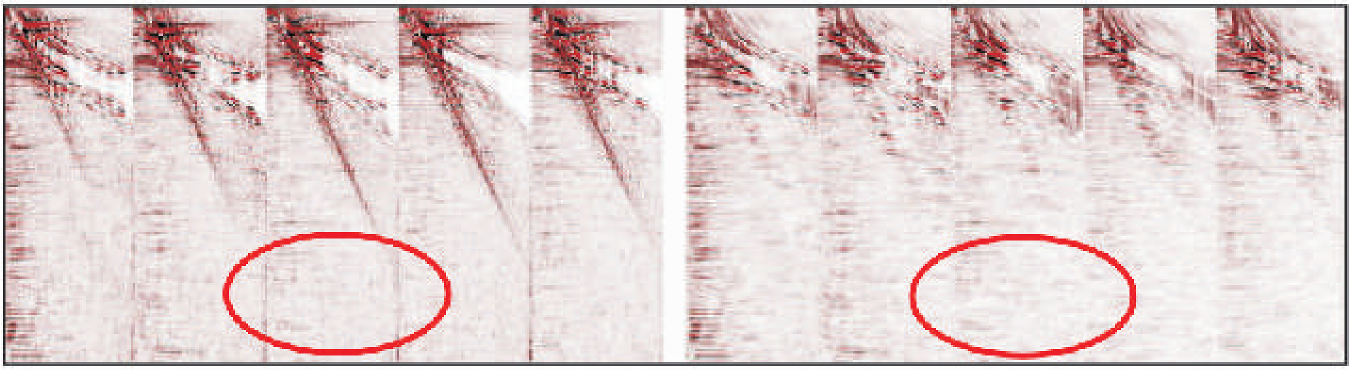

Fig. 4: CDP gathers before and after pre-migration final noise attenuation

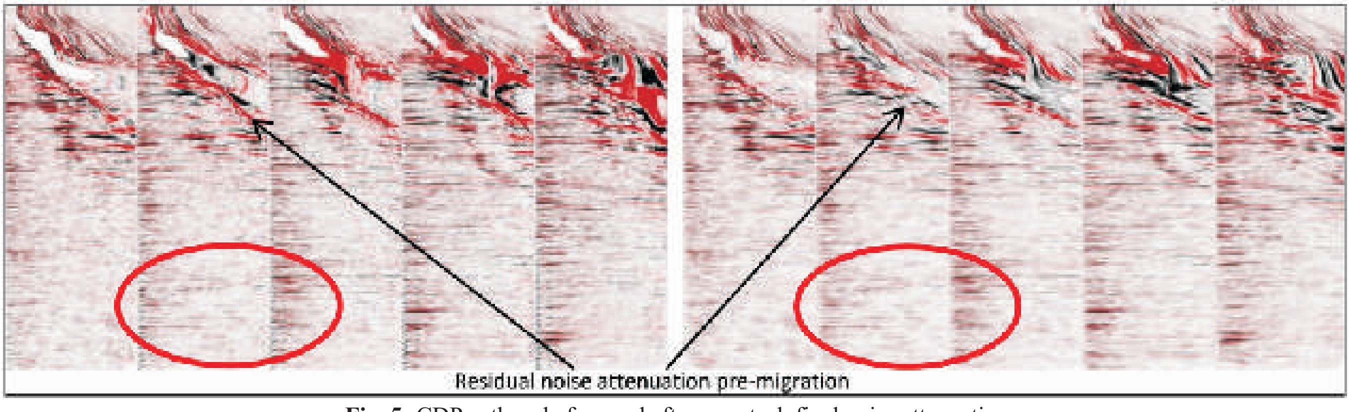

Fig. 5: CDP gathers before and after pre-stack final noise attenuation

frequency sub-basalt primary signal and minimise both coherent and incoherent noise. Post migration noise attenuation was also performed carefully for the best post-migration and stacking response.

Imaging results

Significant improvement to the intra and sub-basalt image is shown after re-processing. A comparison between the new processed and vintage processing is show for few lines.

Conclusion

Area specific workflows based on the complexities of the area in term of geology and data guide in designing an effective processing workflow. We have developed a strategically effective processing work-flow for sub-basalt imaging of long offset data from this study area. Significant improvements have been achieved with this work-flow for sub-basalt imaging. The key points to the success of the processing project are:

- Effectively boosting of the low frequency component (Clari-Fi® Amplio®) of the seismic data.
- Application of concurrent developments in the techniques for the elimination of complex multiples such as HMT® and SMELT®.
- Careful design and implementation of multi domain noise attenuation techniques.

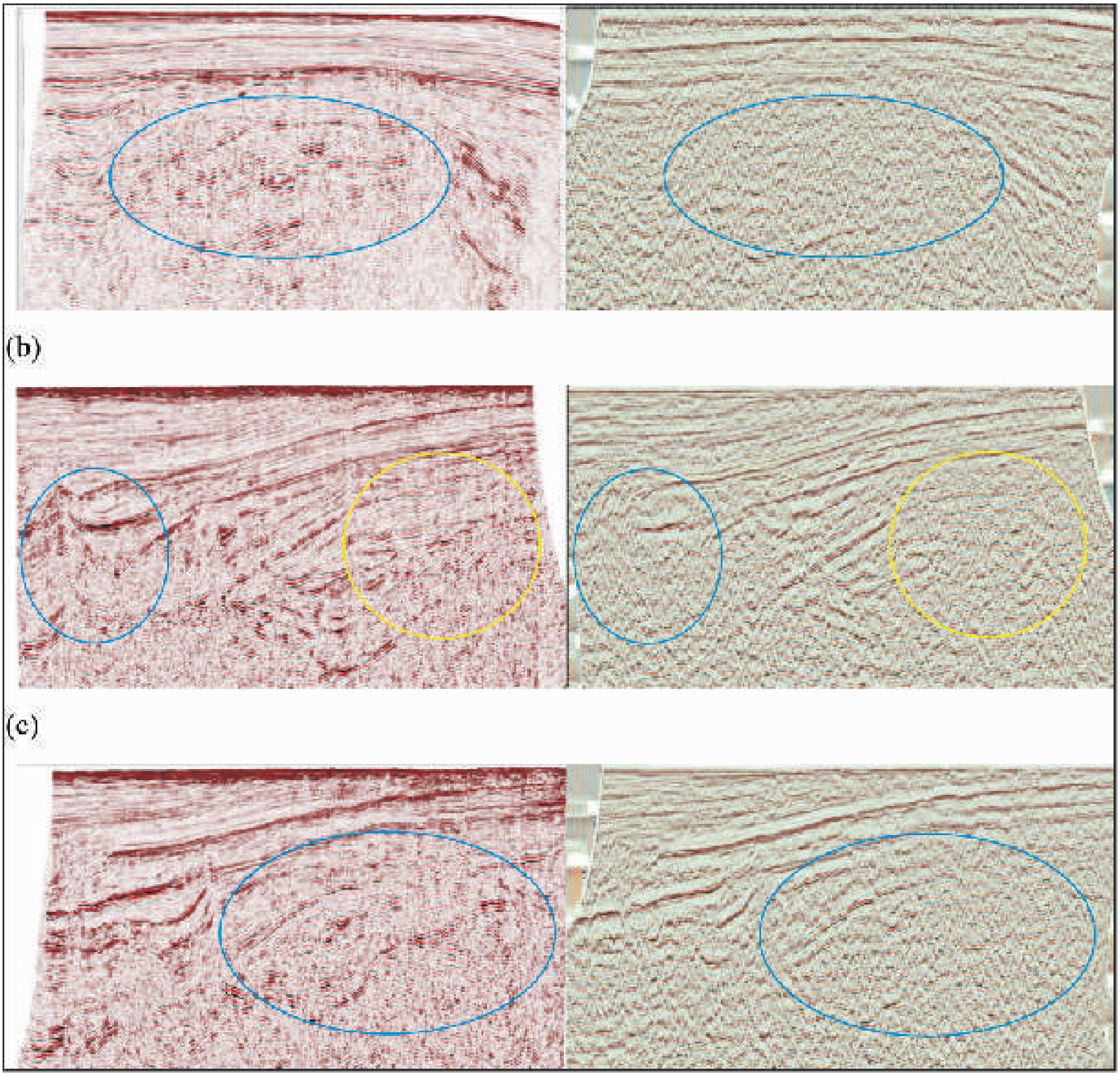

Fig. 6: (a, b & c). Re-processed (left) vs vintage (right) imaging results

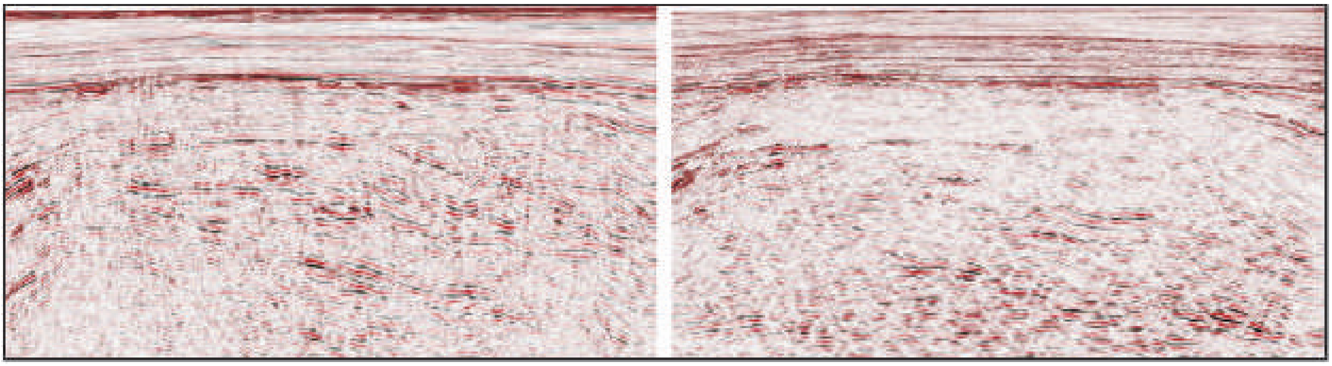

Fig. 7: Re-processed (left) vs 3D-vintage (right) imaging results

Acknowledgement

The authors would like to thank ONGCL, India for permission to show the data examples. Thanks expand to TGS management for the permission to publish this work and all the processing team members who offered their talents and tremendous efforts to get this work done successfully.

References

Anthony Hardwick, Carl Lang, Bent Kjølhamar, Stepwise Multiple Elimination using Linear Transforms: An alternative approach to SRME for stacking multiple - free near offsets in the Barents Sea, SEG Technical Program Expanded Abstracts 2010: 3426-3430.

Hassan Masoomzadeh, Anthony Hardwick, High-resolution Moveout Transform; a robust technique for modeling stackable seismic events, SEG Technical Program Expanded Abstracts 2012: 1-5.

K. W. H. Lau, R. S. White, P. A. F. Christie, Low-frequency source for long-offset, sub-basalt and deep crustal penetration, The Leading Edge Jan 2007, Vol. 26, No. 1, pp. 36-39.

N. Woodburn, A. Hardwick, T. Travis, Enhanced low frequency signal processing for sub - basalt imaging, SEG Technical Program Expanded Abstracts 2011: 3673-3677.

R. Hobbs and D. Snyder, Marine seismic sources used for deep seismic reflection profiling, First Break, Vol 10, No 11, November 1992, pp. 417-426.