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Demultiple of High Resolution P-cable Data in the Norwegian Barents Sea - An Iterative Approach

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SUMMARY

P-Cable seismic data provides both improved temporal and spatial high resolution imaging relative to conventional narrow azimuth acquisition. This has been used with success to image shallow Jurassic prospects in the Norwegian Barents Sea analogous to the Wisting Discovery in the Hoop area. A limiting factor due to the nature of the acquisition design has been the inability to image below the water bottom multiple arrivals. For the first time a successful demultiple strategy is presented, applied to data in the southeast Barents Sea with an example taken from the latest acquisition campaign.

A data driven, iterative approach is taken to minimise the error of the predicted multiple in the secondary removal phase. Through conservative use of both simultaneous and curvelet domain adaptive subtraction schemes the P-Cable window is extended to image secondary targets within the deeper Triassic sequence. The underlying conventionally acquired seismic data are then compared to benchmark and assess the quality of the results achieved.

Introduction

Data acquired using the P-Cable system can be used for high-resolution 3D and regional 2D surveys. Using a high frequency source and a tight streamer configuration both the vertical and spatial resolution is significantly increased compared to conventional acquisition. In a joint venture between WGP, P-Cable 3D Seismic and TGS the first multi-client survey was undertaken in the Norwegian Barents Sea in 2014 in the Hoop area. This focused on shallow exploration targets in the mid Jurassic Stø formation analogous to the Wisting discovery. The regional 2D cruise lines were processed in almost real time to identify areas of interest and acquire small 3D surveys within the same survey. Deghosting of these data gave broadband images in unprecedented detail of potential reservoirs in this area, though fortuitously above the first water bottom multiple.

In 2015 another multi-client P-Cable campaign commenced in the Barents Sea, starting again in the Hoop area but moving to the southeast Barents Sea (BSSE) with Figure 1 showing the extent of the 2D swaths acquired. These were again used to plan and acquire small 3D surveys within the same acquisition window. In this area water depths are shallower and the water bottom multiple cuts through the shallow prospective Jurassic plays. The ability to remove this and other higher order multiples from the data is desirable but the nature of the acquisition makes it difficult to apply moveout based demultiple techniques due to the very low fold and limited offset range available. Convolutional, data-driven methods such as SRME for predicting and removing surface multiples offer the most chance of success, provided that the differences between the predicted multiples and the actual multiples are minimised before the adaptive subtraction process.

Here we present a successful strategy in the BSSE area in the 23rd block area where we apply iterative SRME attempting a closed feedback loop in three passes to obtain a model. A cascaded pass of SRME is applied on top of the least-squares adaption result from a previous iteration, to produce a secondary 'residual' model, while passing both models into a simultaneous least-squares adaption scheme. The final adapted model is then subtracted in the curvelet domain. For the first time, through very careful consideration of amplitudes we not only extend the usable window of the P-Cable data in the Jurassic but also achieve good imaging in secondary and deeper targets within the Triassic Snadd and Kobbe formations.

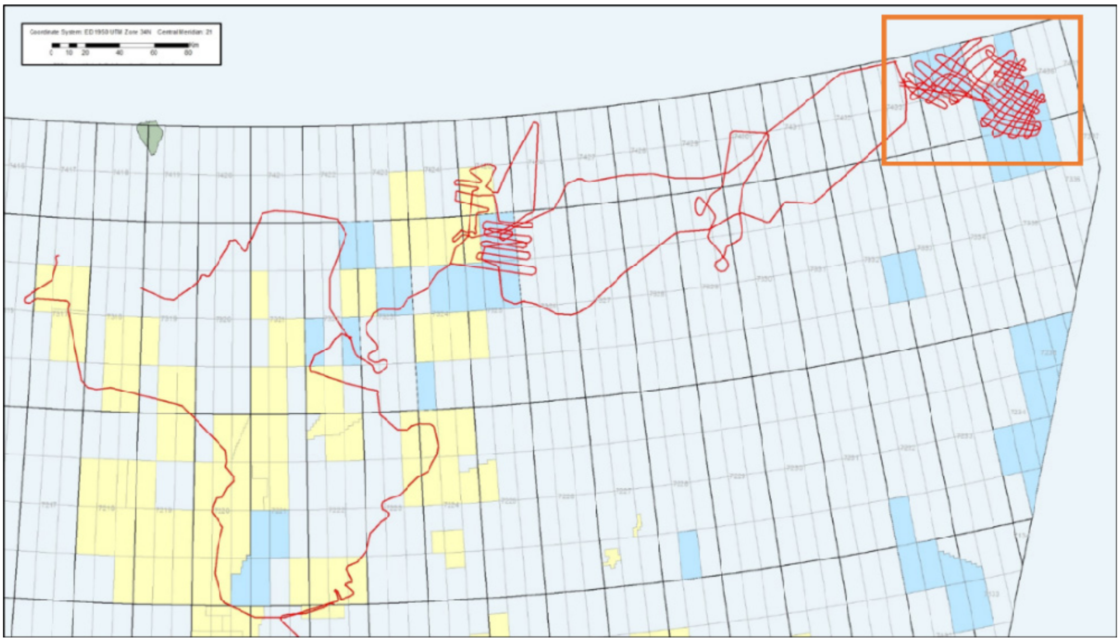

Figure 1 *2D P-Cable swaths acquired in 2015 within the Norwegian Barents Sea. Held license blocks are highlighted in yellow and those announced 23rd round blocks shown in blue. The area outlined in orange covers the data described here.*

Acquisition and pre-processing

The P-Cable system consists of a single source and typically 16 streamers hung from a cross-cable connecting two paravanes maintaining an approximate catenary (Figure 2). Each streamer consists of 8 receiver groups at 3.125 metre spacing with an ideal cable separation of 12.5 metres. Data is recorded at a 0.5 ms sample rate and with a record length of 4 seconds. Source-receiver offsets due to the catenary, irrespective of cable have a considerably small range typically about 60-90 metres for a 2D swath in the BSSE area. The airguns and cables are both at 2 metres with a depth variation tolerance of ± 0.75 metres expected in the receivers.

The data were resampled to 1 ms with swell noise attenuation, designature for the bubble pulse and a dedicated deghosting method applied to remove both the source and receiver side ghosts (Ratnett *et al*., 2015). The true source-receiver offset, due to the catenary, shortens towards the outer cables which is undesirable for SRME despite the narrow spread. For this reason extrapolated stacking velocities from TGS' reprocessed underlying regional 2D BSSE survey were used to regularise the offsets for each individual cable via differential NMO. Ideally for SRME sources and receivers should be co-located, in this instance we interpolated the shots at a 12.5m interval down to 6.25m in the common channel domain to give a 2:1 ratio.

Demultiple Method

SRME techniques involve two stages, multiple prediction and primary-multiple separation. Amplitude errors and imperfections in the predicted model create the challenge in the separation stage, particularly in shallow water. For P-Cable data there is no margin for error as short matching filters are required for conventional least-squares (LS) adaption methods to be successful.

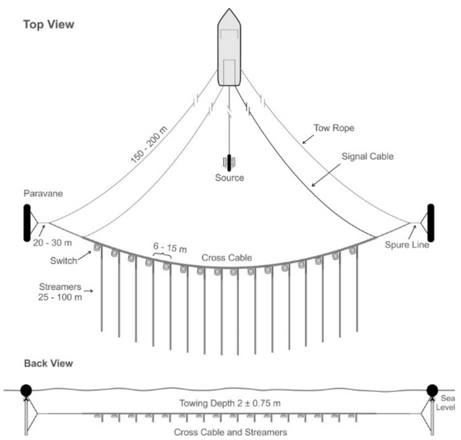

Figure 2 *Example layout for P-Cable acquisition (courtesy of P-Cable).*

Here we modify the scheme of Berkhout and Verschuur (1997) with the demultiple strategy outlined in Figure 3. Initially an iterative approach is taken whereby the LS subtracted results are convolved with the input data containing multiples. A straightforward pass of SRME where the data is convolved with itself generates a model with significant amplitude errors due to the cross-talk of strong multiples (Fig. 4(b)). After three iterations convergence is met in terms of amplitude (Fig. 4(c)). In the first iteration we opt to convolve the data with itself but with one input muted above the first water bottom multiple. In the second round this is extended further and eventually the full record length is used. A secondary residual multiple model is obtained by convolution of the LS adapted result from the third iteration with itself (Fig. 4(d)).

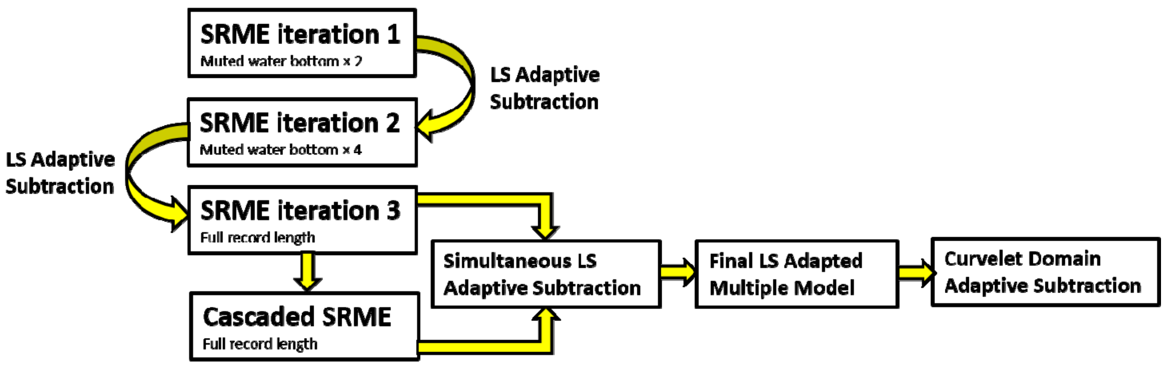

Figure 3 *Iterative multiple prediction and adaptive subtraction removal scheme.*

Both models are passed into a simultaneous LS adaption scheme where weights are calculated based on their similarity to the input data (Zhai et. al, 2015); summation forms a final LS adapted model (Fig. 4(e)). The last subtraction is undertaken in the curvelet domain (Herrmann et. al, 2005), offering superior subtraction of multiples with overlapping primary events due to dip separation and improved handling of lateral phase and amplitude variations.

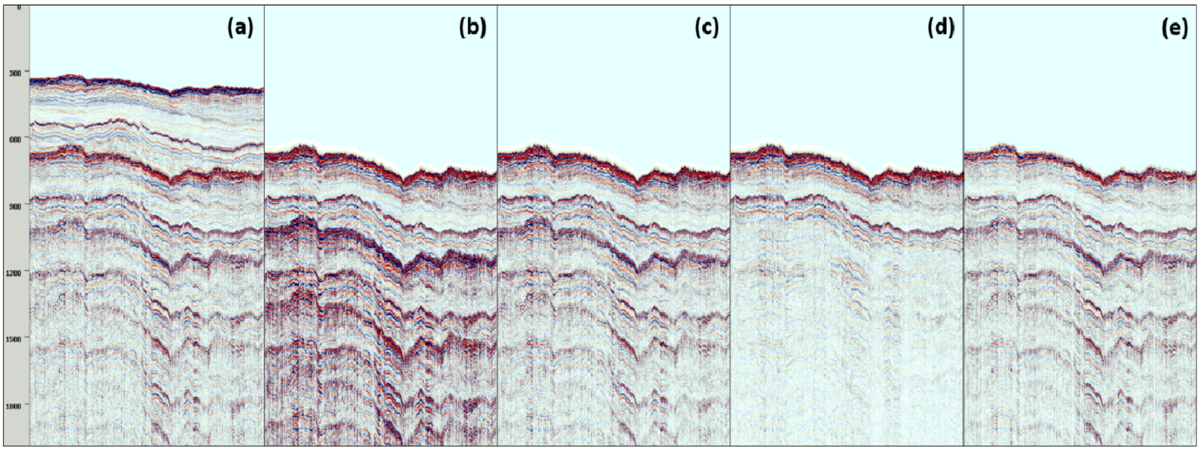

Figure 4 *(a) Input stack of all cables; (b) conventional SRME model demonstrating amplitude errors, (c) SRME model after 3 iterations, (d) cascaded model and (e) adapted model from simultaneous subtraction of the models shown in (c) and (d).*

Results

Figure 5 demonstrates the benefit of curvelet subtraction over a straight subtraction of the model shown in Figure 4(e) relative to the input in a region where the water bottom is particularly rugose. Continuity of the underlying primaries is enhanced in the zone of most exploration interest between the Jurassic Stø and Triassic Kobbe formation. Figure 6 shows a comparison with an underlying 2D BSSE long offset line which was used to ground-truth the results of the P-Cable demultiple. In this comparison we show that a similar level of demultiple is achieved but with the increased bandwidth anticipated. Internal multiple is evident after removal of free surface multiples in the lower Triassic and below which would require further attention if deeper imaging is required. This is attenuated on the conventional long offset 2D data through stacking of much higher fold data and inner trace muting, which is not possible for the P-Cable data.

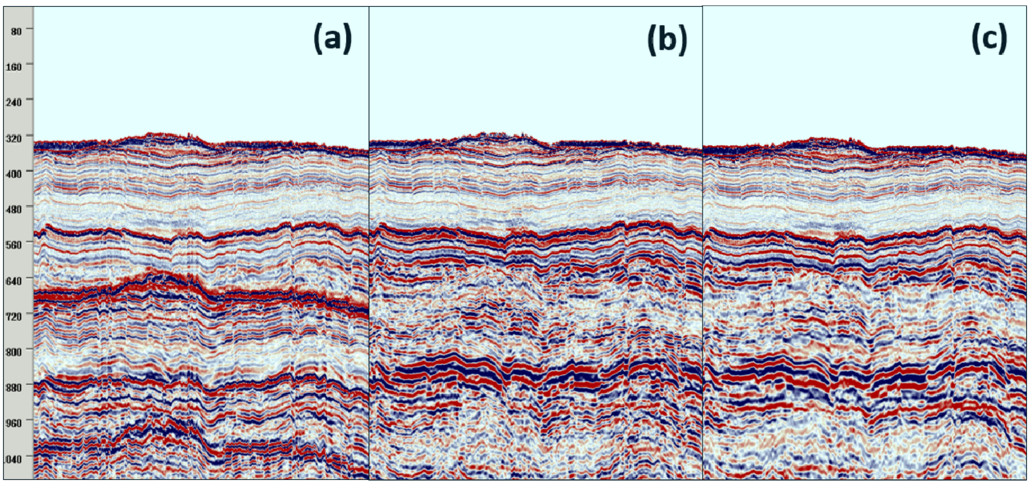

Figure 5 *(a) Input data; (b) Straight subtraction of the final model (LS adapted) shown in figure 4(e) and (c) after curvelet subtraction of the same model. A full trace equalisation is applied to all panels.*

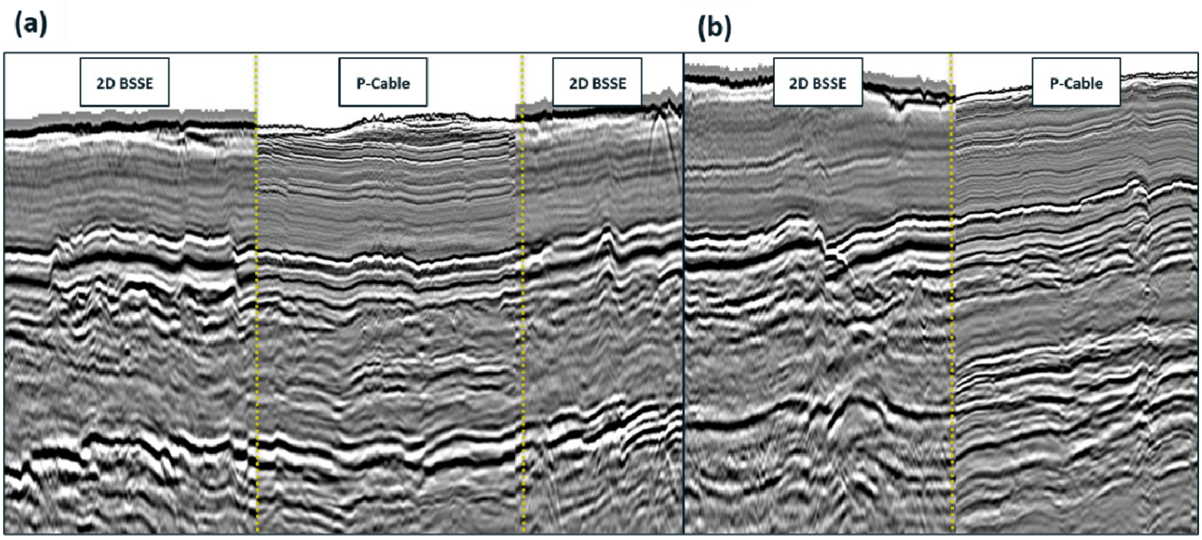

Figure 6 *Comparison of P-Cable data after demultiple compared to an overlapping segment of the regional 2D BSSE dataset and (b) a brute intersection between the two.*

Conclusions

Deghosted P-Cable data is a valuable and proven technique for obtaining high resolution data over shallow prospects in the Norwegian Barents Sea. To date its use has been limited by the interference of free surface multiples particularly in the BSSE area. Sensitive and robust convolutional multiple prediction and adaptive subtraction schemes extends the P-Cable imaging window to deeper targets within the Triassic. Underlying long offset datasets provide a reference for the results obtained.

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