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Technological Advancements in Broadband Processing – A Reprocessing Case History from the Barents Sea

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Summary

In 2012 TGS acquired and processed 2500 km2 of narrow azimuth 3D streamer data over the Finnmark Platform, offshore northern Norway, and a further 3800 km2 in 2013, named FP12 and FP13 respectively. The FP12 data were originally processed through a conventional bandwidth sequence in 2012 whilst in 2013, with the emergence of processing based deghosting technology, the FP13 data were processed through a broadband sequence. In the years since 2013, developments in seismic preprocessing technology have resulted in superior tools and solutions with which to address the major challenges that the Finnmark Platform data presents to imaging, such as: high levels of acquisition noise caused by northern latitude marine conditions, notches in the amplitude spectra caused by the interference of ghost reflections and a strong multiple trail set up by the hard seabed surface. Utilising these technological advancements, full reprocessing of the Finnmark Platform data was undertaken resulting in a superior image of the subsurface and single, continuous broadband dataset. Here we discuss the key processing technologies that contributed to the successful reprocessing.

Introduction

In 2012 TGS acquired and processed 2500 km^2 of narrow azimuth 3D streamer data over the Finnmark Platform, offshore northern Norway, and a further 3800 km^2 in 2013, named FP12 and FP13 respectively (Figure 1). The main targets in the area are within the shallow siliciclastic and carbonate lithology, located in a northward dipping platform consisting of subtle stratigraphic traps of Paleozoic age, as well as Cretaceous, Jurassic and Triassic leads along the flank of the Hammerfest and Harstad Basins. The FP12 data were originally processed through a conventional bandwidth sequence in 2012 whilst in 2013, with the emergence of processing based deghosting technology, the FP13 data were processed through a broadband sequence.

A number of active exploration licences exist on the Finnmark Platform, one of which, PL764, covers 762 km^2 of the FP13 survey and is operated by Lundin Norway. Within this area Lundin Norway and licence partners identified a Late Permian prospect on existing 2D seismic, and used the FP13 3D data to further evaluate the lead. Whilst the prospect was imaged in the 2013 processing, the data quality was not deemed adequate to fully derisk the targets and so a reprocessing effort was undertaken.

In the years since 2013, developments in seismic preprocessing technology have resulted in superior tools and solutions with which to address the major challenges that the Finnmark Platform data presents to imaging, such as: high levels of acquisition noise caused by northern latitude marine conditions, notches in the amplitude spectra caused by the interference of ghost reflections and a strong multiple trail set up by the hard seabed surface. To utilise these technological advances full reprocessing of the entire 6300 km^2 Finnmark Platform data commenced in 2017 to create a superior image of the subsurface and provide a single, continuous broadband dataset. At the same time, after initial preprocessing up to and including SRME, a subset of data covering the Lundin Norway area branched off for a more bespoke processing route focusing on the specific targets and challenges encountered within that area. Here we discuss the key processing technologies that contributed to the successful reprocessing of the Finnmark Platform data.

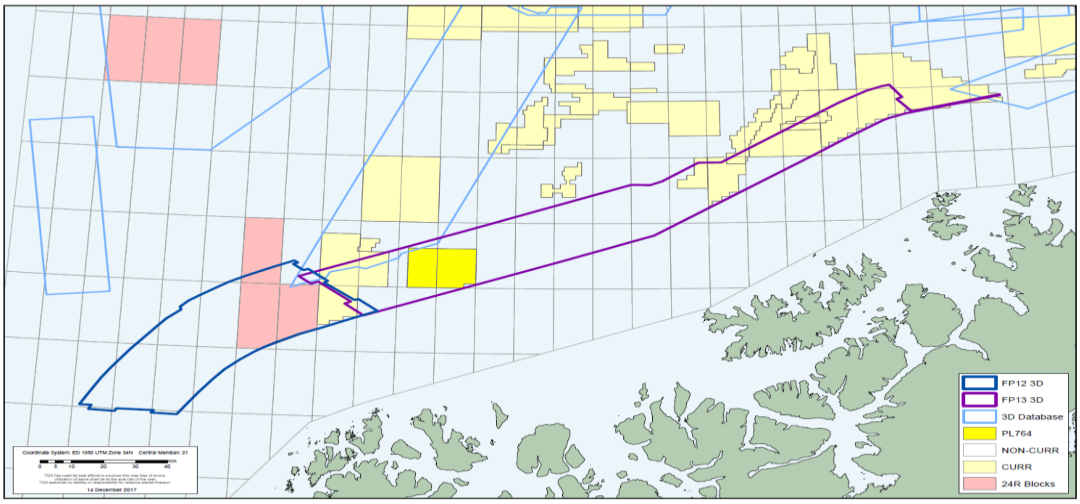

Figure 1 *Map showing the location of the reprocessed Finnmark Platform 3D data. Outline of FP12 acquisition in blue, FP13 acquisition in purple and the Lundin operated area shaded dark yellow.*

Noise attenuation

As is common for northern latitude oceans, rough sea conditions were experienced during acquisition resulting in high levels of noise present in the data (Hardwick et al., 2014). For successful broadband reprocessing it was essential that this noise was sufficiently attenuated prior to deghosting for two reasons: (1) the deghosting operation will boost the low frequencies with no discrimination between signal and noise, and (2) the noise will smear through the domain transformations used in deghosting workflows. To achieve the high level of noise attenuation required, median filtering in a simultaneous multidomain approach was employed, enabling significant levels of swell noise to be modelled and subtracted without the need for sorting to multiple domains and cascading the filters (Figure 2). The multidomain method is accomplished by analysing several adjacent shot gathers at the same time, enabling a simultaneous review of traces from different domains in a single computation (Masoomzadeh et al., 2017).

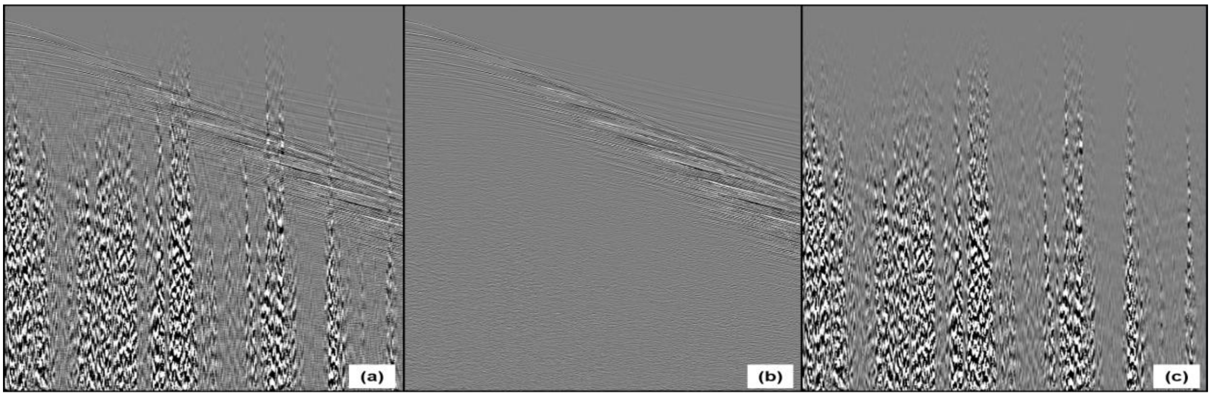

Figure 2 *Example FP13 shot gathers acquired within the Lundin operated area; 2(a) input to noise attenuation, 2(b) after application of multi-domain denoise (MDD), 2(c) difference plot.*

Variable depth streamer deghosting

The Finnmark Platform data were acquired using a flat streamer cable deployment where there is no intentional variation in receiver depth along the cable. In practice constant receiver depth acquisition never occurs because the receivers do not remain at their predefined depths, but also the sea surface is not flat and therefore the depth to receiver varies accordingly. To compensate for this, we perform a fine tuning of the recorded receiver depths to obtain a measurement of the *true* receiver depth, which is a representation of the depth of receiver (relative to mean sea level) and the sea surface variation combined. Owing to the explicit relationship between the receiver depth and its corresponding notch location in the frequency domain ($f_n = v_w / 2d\cos\theta$, where v_w is water velocity in *m/s*, d is depth to receiver in m and θ is the angle of incidence in degrees), fine tuning is possible through an analysis of the notch location for each individual trace in the *f-x* domain (Hardwick et al., 2015). We achieve this by conducting a search for the minimum amplitude in the vicinity of the expected notch location based on the recorded measurements. Once we have fine-tuned the recorded receiver depths, these updated measurements are used to perform accurate deterministic deghosting in the *f-k* domain. Deghosting is performed in the *f-k* domain because the ghost delay time is angle dependent and therefore needs to be addressed with respect to ray parameter.

Shallow water and surface related multiple elimination

The Finnmark Platform is characterised by a hard, locally rugose seabed surface which sets up a strong trail of water layer and peg-leg multiples that contaminate the relatively shallow sedimentary targets. To address these, a robust and exhaustive demultiple sequence was employed, providing significant improvements over vintage processing through a convolution-based demultiple approach. Shallow Water Multiple Elimination (SWME), a method involving the convolution of the input data with a ray-traced model of the water layer Green’s Function, was used to predict short-period water layer multiples, while Surface Related Multiple Elimination (SRME), a method involving convolving the input data with itself, was used to predict longer period higher order surface related multiples. A key step to the success of this demultiple scheme was achieved in the subtraction stage, which was performed in two steps. The first step involved the adaption of all three multiple models, source side SWME, receiver side SWME and the SRME model, using a weighted simultaneous least squares algorithm. This provides a single multiple model incorporating optimal predictions from all input models. The second stage consisted of the subtraction of this single model, which was implemented through a multidomain least squares adaptive subtraction (Figure 3). The multidomain least squares adaption algorithm utilises the same multidomain methodology as described for noise attenuation; several adjacent gathers are analysed simultaneously, providing increased statistics from a more localised area for adaption.

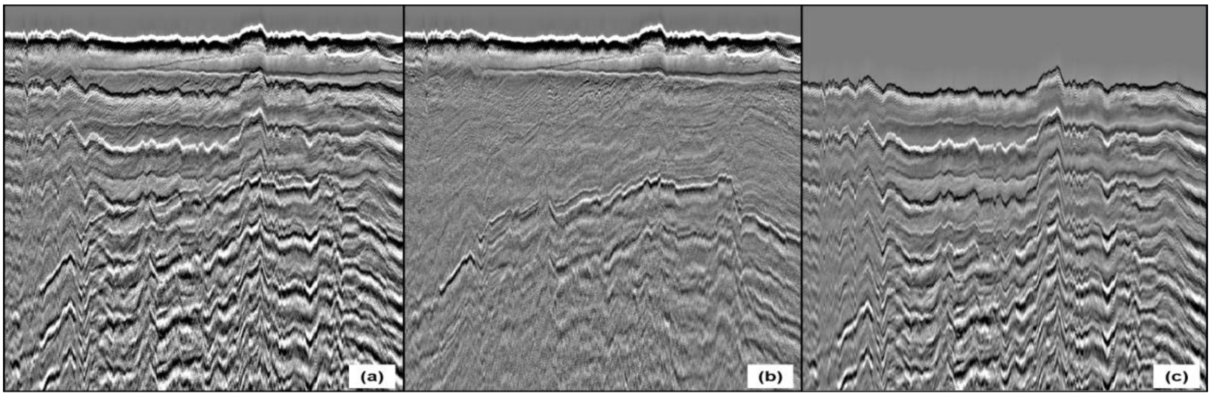

Figure 3 *Example FP13 stack in the Lundin operated area; 3(a) input to SWME-SRME, 3(b) output from SWME-SRME subtraction, 3(c) difference plot.*

Diffracted multiple attenuation

Another consequence of the hard seabed and its locally rugose nature is the presence of strong diffracted multiple energy generated at the water bottom. These exhibit strong amplitudes which contaminate the shallow section if not attenuated prior to migration. Whilst conventional SWME/SRME does attenuate some diffracted multiple, often the apex energy, it struggles in shallow-water narrow-azimuth (NAZ) surveys due to poor subsurface illumination, out of plane reflections and finite aperture multiple modelling. To deal with the residual multiple, we employed a method of Diffracted Multiple Attenuation (DMA) which involves modelling the multiples in the common-p domain before adaptively subtracting them in the curvelet domain (Figure 4). The curvelet domain proved particularly useful for the adaption of the DMA model, due to the superior separation of primary and multiple in terms of frequency and dip, compared to that which is possible in the *t-x* domain.

Temporally and spatially varying Q compensation

The final processing step which is key to providing true broadband seismic data is the compensation for the earth filter effect. The earth filter effect, also known as the seismic quality factor (Q), quantifies the progressive loss of amplitude and phase distortion with increasing travel time. We can estimate the effective Q (Q_{eff}), the inseparable combination of intrinsic and apparent Q, from our recorded surface seismic data. The original processing on the Finnmark Platform compensated for Q_{eff} by using a singular value correction. While this was standard practice at the time, it did not acknowledge the localised variations in subsurface lithology and therefore compromised the true broadband nature of the output. For the reprocessing, we have utilised a stable and automated algorithm based on the method of spectral ratios (Dasgupta & Clark, 1998) to derive a temporally and spatially varying Q_{eff} field which is structurally consistent and conforms with geology.

Conclusions

Significant improvements in imaging of the Triassic and Permian sequence are achieved through the application of modern processing technology. Notable uplift over the vintage processing is achieved in terms of signal-to-noise levels, broadband frequency content and reduced multiple content (Figure 5). Improvements in data quality within the Lundin Norway operated area have enabled a more detailed and confident interpretation of the leads within the licence.

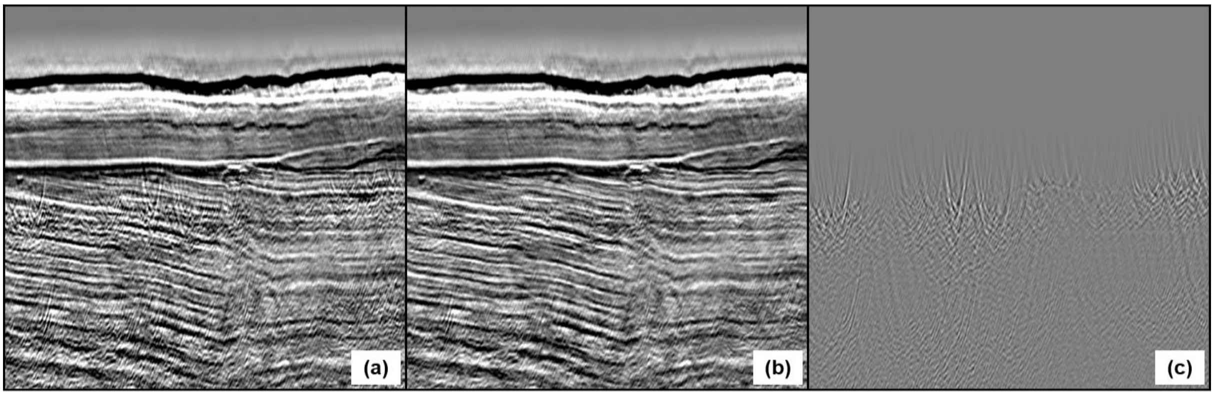

Figure 4 *Example migrated stack in the Lundin operated area; 3(a) input to DMA, 3(b) output from DMA subtraction, 3(c) difference plot.*

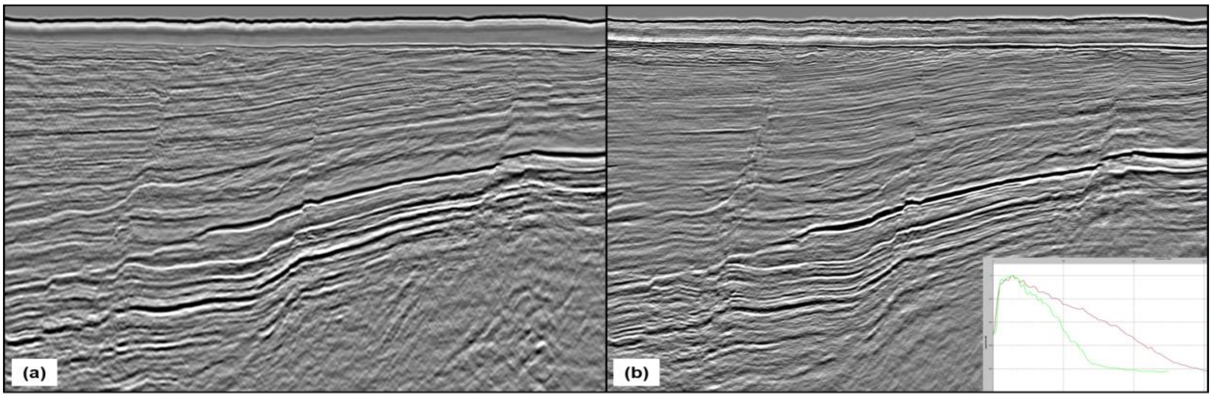

Figure 5 *Example processed migration in the Lundin operated area; 5(a) 2013 processing, 5(b) 2017 reprocessing. Corresponding normalised amplitude spectra are shown (2013 in green, 2017 in red).*

Acknowledgements

The authors would like to express our thanks to all colleagues involved in the Finnmark Platform reprocessing project, and to TGS, Lundin Norway AS, Bayerngas Norge AS and Maersk Oil for permission to show the datasets.

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