Enhanced Subsurface Illumination of Shallow Bright Spots with Separated Wavefield Imaging

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SUMMARY

In the shallow water environment found in parts of the Barents Sea, conventional imaging struggles to provide good imaging of the near surface. This is due to the lack of near offsets (angles) in typical marine seismic data, caused by the large minimum distance between the source and receivers. Here, we present a method that uses separated (up- and down-going) wavefields provided by dual-sensor streamer technology to construct images and image gathers that span a full range of incidence angles. In this method, each receiver is used as a virtual source, providing a dataset that has complete coverage of zero- and near-offsets everywhere under the seismic spread. This provides near-angles for shallow targets that are not sampled by the primary wavefield, enabling amplitude versus angle (AVA) analysis to be performed. In this study AVA results are used to characterize bright spots as a direct hydrocarbon indicator.

Introduction

A 5,600 km^2 seismic survey covering the Northern area of the Barents Sea was acquired during the summer of 2014. A limited weather window and aggressive deadlines meant that acquisition efficiency was the priority. Consequently, the vessel deployed 10 deep-towed, dual-sensor streamers, 7km long and 75m apart. This relatively small streamer separation was intended to improve illumination of shallow targets. Throughout a large portion of the Barents Sea, the main plays consist in shallow bright and/or flat spots (Figure 1). The high amplitude is a response to the combination of lithology and fluids. High and low gas saturation, as well as oil appears with a similar seismic response, making it a challenge to find a discriminating Direct Hydrocarbon Indicator (DHI).

Acquiring 3D towed-streamer marine seismic in shallow water involves a compromise between efficiency and near-surface sampling. The wider the surface spread, the larger the distance between sail lines. This results in more efficient data gathering, but can suffer from acquisition footprint due to the lack of small offsets recorded on the outer cables. The lack of near-offset data at the swath boundaries leaves shallow illumination holes. Such footprint in the image can limit our ability to pick velocities based on gather flatness, and prevent AVA studies due to the lacking near data coverage.

Whitmore et al. (2010) demonstrated that sea-surface reflections, which are captured in the down-going wave of multi-sensor streamer acquisitions, can be used as virtual sources providing the near-surface information missing from primary reflections. This has been used as part of the complete wavefield imaging (CWI) workflow to unravel shallow heterogeneities present in the North Sea, enabling more accurate depth models (Rønholt et al., 2014). In the case of the Barents Sea, sea-surface reflections can provide a direct and improved image of shallow targets, along with full angle gathers and the potential for a more discriminating DHI.

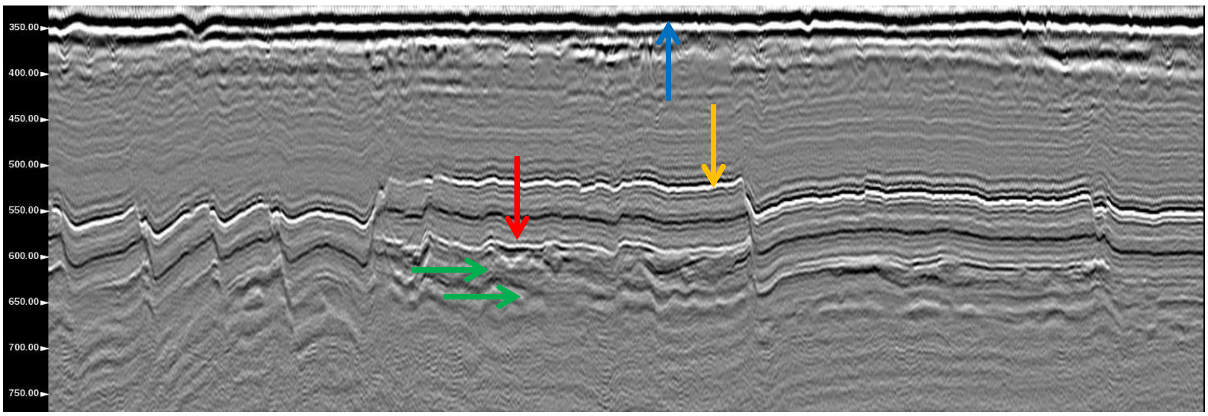

Figure 1 Kirchhoff PSDM reference image illustrating the shallow targets. Water depth is roughly 350m (blue arrow) and a distortion of the wavelet is seen when imaging with reflections, indicating that some events are from post critical angle energy. The orange arrow points to the Base Cretaceous Unconformity (BCU), the red arrow to the level of the bright spots and the green arrows to flat spots observed in the data.

Methodology

Conventional wavefield extrapolation depth migrations with primaries back propagate the upcoming data as receiver wavefields, and forward extrapolate a synthetic point source. An image is formed wherever these two wavefields coincide in time and space. Imaging with separated wavefields is done after carrying out a wavefield separation using a dual-sensor recording. The down-going wavefield is used as source and the up-going wavefield as the receiver wavefield (Whitmore et al., 2010). This turns each receiver into a virtual source, increasing the source sampling and coverage at the surface.

The improved data coverage mitigates acquisition footprint and provides enhanced angular illumination in the shallow sub-surface (Lu et al., 2014)

A deconvolution imaging condition is used because of the complexity of the up- and down-going wavefields' interaction. This reduces the cross-talk noise generated from unrelated correlation of up- and down-going wavefields. Subsurface offset gathers are formed using an extended imaging condition. Angle gathers are generated from subsurface offset gathers after applying a radial trace transforms. As shown by Lu et al. (2014) the angle gathers obtained from imaging of separated wavefields can illuminate areas not covered by primary reflection migrations.

Results

The Barents Sea is known for its hard seafloor due to older, compacted sediments exposed by uplift and erosion during the last ice age (Grogan et al., 1999). Locally, slightly slower velocity Quaternary sediments are exposed. Highly compacted shales exhibit an extreme anisotropy regime with horizontal velocities as much as 35% higher than vertical velocities (Rønholt et al., 2008). The velocity model was built without access to well data within the survey area. Regional anisotropy trends were used for the starting model and successively update through a combination of reflection tomography and full waveform inversion (FWI).

The velocity model after FWI was used to image both primary reflections and sea-surface reflections with separated wavefield imaging. The resulting angle gathers show improved illumination (Figure 2). The primary reflection gathers lack contributions to the near-angles due to the relatively large minimum offset acquired relative to target depth. At the target zone (550-650m depth) the minimum angle varies from 15 to 20°. The sea-surface reflection gathers display a full angular coverage from 0 to ~50°.

A comparison of the partial angle-stacks from the migration using separated wavefield imaging is shown in Figure 3. For the selected line we observe both class two (close to zero intercept and negative gradient) and class three (negative intercept and gradient) AVA behaviors. There are a number of publically released wells in the Barents Sea with target sands at similar depths below the mud line. Modelling gathers based on fluid substitution in equivalent geological settings have been performed and show that AVA class one is indicative of brine sands, class two of oil sands and class three of gas sands.

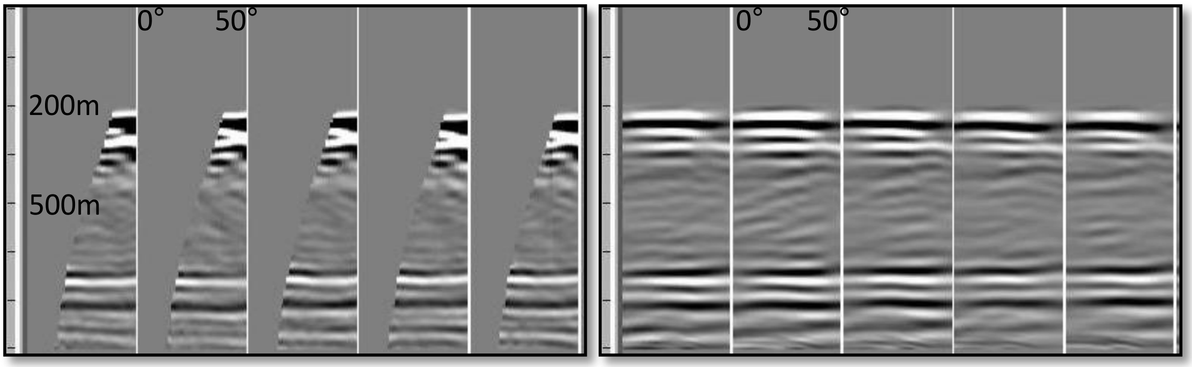

***Figure 2** Angle gathers, imaging with reflections (Kirchhoff PSDM, left) versus imaging with separated wavefields (right). The lack of near angular coverage is evident in the reflection migrated gathers.*

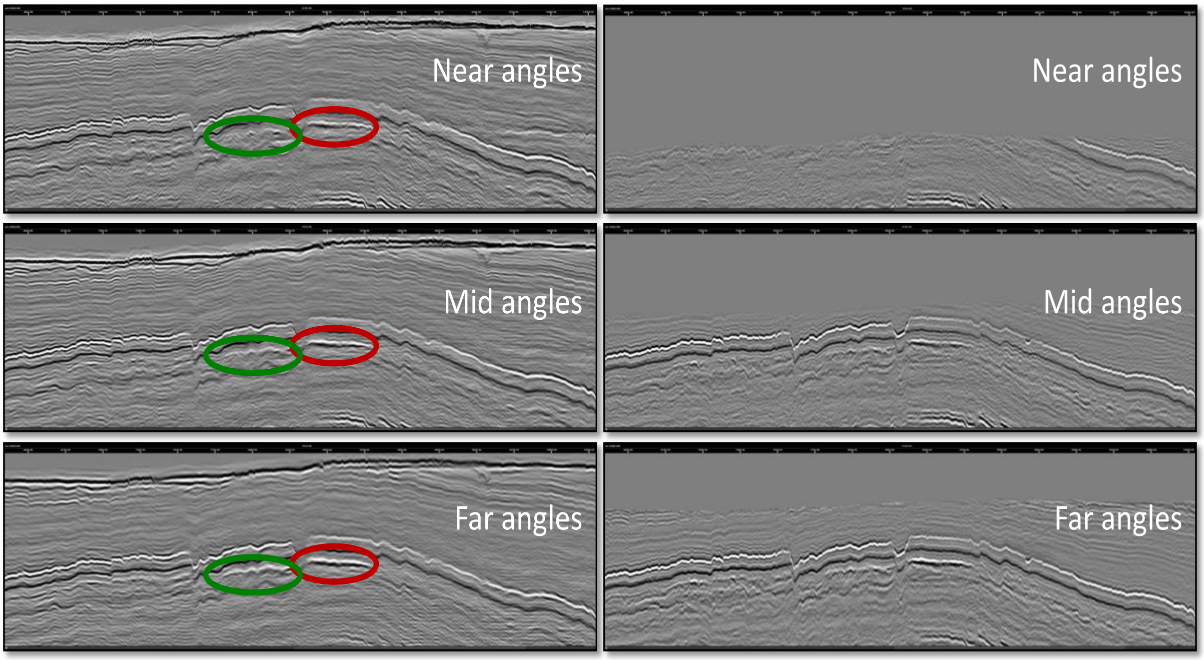

Figure 3 *Partial stacks from separated wavefield imaging (left) versus primary reflections (Kirchhoff PSDM, right). Near, mid and far angle stacks comprise data from 5-15°, 15-25° and 25-35° respectively. With the near angular coverage a clear discrimination of class two (green circle) and three (red circle) AVA behaviour of the bright spots is possible.*

Conclusions

Imaging shallow targets with primary reflection energy typically require expensive and inefficient seismic acquisition to preserve a small enough near-offset throughout the survey. In the Barents Sea this drawback is amplified by the limited weather window available for seismic acquisition.

Dual-sensor streamers, in addition to increasing the weather window through deep-tow, have technical advantages that help mitigate the challenges of shallow imaging. They provide access to enhanced low frequencies that are leveraged in FWI model building, but more importantly, allow for wavefield separation to gain access to up- and down-going wavefields. Using separated wavefield imaging circumvents the problem of poorly sampled primary reflections from shallow events. The methodology turns the receivers into virtual sources, providing coverage that is well sampled for the near offsets. Sea surface reflections can sample near-angles much better than primary reflections. We use this to provide a high resolution image of the shallow targets. Sea-surface reflections also provide fully populated angle gathers enabling AVA analysis. Using separated wavefield imaging enables us to interpret the shallow bright spots in the Barents Sea South East exhibiting class one, two and three AVA behaviors.

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References

Grogan, P., A.-M. Østvedt-Ghazi, G. B. Larssen, B. Fotland, K. Nyberg, S. Dahlgren, and T. Eidvin, [1999] Structural elements and petroleum geology of the Norwegian sector of the northern Barents Sea. *Proceedings of the 5th Petroleum Geology Conference*, 247-259.

Lu, S., D. Whitmore, A. Valenciano, and N. Chemingui [2014] Enhanced subsurface Illumination from separated wavefield imaging. *First Break*, **32**(12), 87-92.

Rønholt, G., H.A. Aronsen, T. Hellmann, and S. Johansen [2008] Improved imaging of the Snøhvit field through integration of 4C OBC and dual-azimuth streamer seismic data: First Break, **26**, no. 12, 61–66.

Rønholt, G., Lie, J.E., Korsmo, O., Danielsen, B., Brandsberg-Dahl, S., Brown, S., Chemingui, N., Valenciano Mavilio, A. and Whitmore, D. [2014] Broadband velocity model building and imaging using reflections, refractions and multiples from dual-sensor streamer data. *76th EAGE Conference & Exhibition.*

Whitmore, N.D., Valenciano, A.A., Söllner, W. and Lu, S. [2010] Imaging of primaries and multiples using a dual-sensor towed streamer. *80th SEG Meeting, Expanded Abstracts*, 3187-3192.