

# Capturing the Value of Source-Over-Streamer Acquisition for Velocity Model Building at Barents Sea

N. Salaun<sup>1</sup>, M. Reinier<sup>1</sup>, G. Henin<sup>1</sup>, G. Gigou<sup>1</sup>, A. Wright<sup>1</sup>

<sup>1</sup> CGG

## Summary

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The source-over-streamer configuration has proved its efficiency to enhance subsurface resolution imaging thanks to its ideal geometrical design for seismic data pre-processing. In complex geological area such as Barents Sea shooting above the deep tow streamers also brings some advantages for velocity model building, such as: dense residual moveout information, good signal to noise ratio and a full incidence angle recorded from the water bottom to well separate vertical from horizontal velocity. By adding a front source to the original design, recorded diving waves are now penetrating down to 2 km depth, below the numerous gas pockets present on the region. The combination the reflection information from the clean common imaged gather and the diving wave from the long offsets allows a high-resolution velocity model to be obtained through tomography and full waveform inversion.

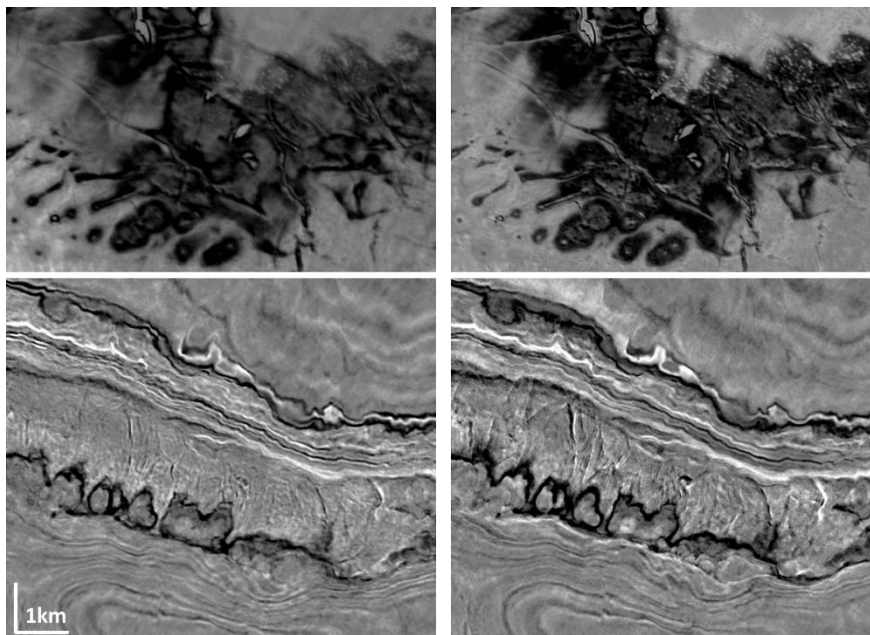
## Introduction

Recent hydrocarbon discoveries made in the Barents Sea reveal a very promising exploration area for the industry. New acquisition designs were implemented to overcome imaging challenges caused by the hard water bottom, numerous gas pockets and shallow reservoirs. These new designs resulted in improved imaging and increased resolution (Garden et al 2017, Lie et al. 2018). Shooting with sources over the streamer has already shown great potential in producing high resolution imaging at all depths in such regions (Dhelie et al. 2018). With its natural fine bin size and the slanted cable allowing good signal to noise ratio at near offset, raw recorded data are ideal to start pre-processing. By recording zero and negative offsets, multiple models are more accurate, leading to a better multiple suppression (Pica et al. 2018).

In complex geological regions and for deeper reservoirs, having access to clean input data for imaging is only solving the first part of the problem. The second challenge is the ability to solve an inverse problem to derive the velocity field from the recorded seismic data. For this second step, shooting above the deep tow streamers also brings some advantages, such as: dense residual moveout (RMO) information, clean low frequency signal and a full incidence angle recorded from the water bottom to well separate vertical from horizontal velocity. While the PreSTM imaging showed impressive improvements compared to conventional towed streamer acquisition over the Loppa High region (Salaun et al. 2019), the result obtained after careful depth imaging shows better event focusing both below the water bottom and deeper, at the Alta target (Figure 1).

Encouraged by image quality obtained on Loppa high area, new acquisition designs were proposed to pursue increasing resolution and imaging quality. A limit of the original design was the lack of long offsets, not used in imaging with such a target, but important for velocity model building and notably FWI. With a maximum offset of 3.5 km for the Loppa acquisition, the maximum penetration depth of the diving wave was around a kilometer which does not take into account all gas pockets present on the area.

A new acquisition design was shot on the Utsira area with six sources widely separated on top of the streamer and, for one sequence, a test to add a triple source at the front of the cables towed by the receiver boat. These front sources provided long offsets which, after proper source separation (Vinje and Elboth, 2019), can be used for FWI. A similar design combining improved near offset coverage and long offset information, with only one front source, was chosen to acquire the 5000 sqkm Greater Castberg area in summer 2019.

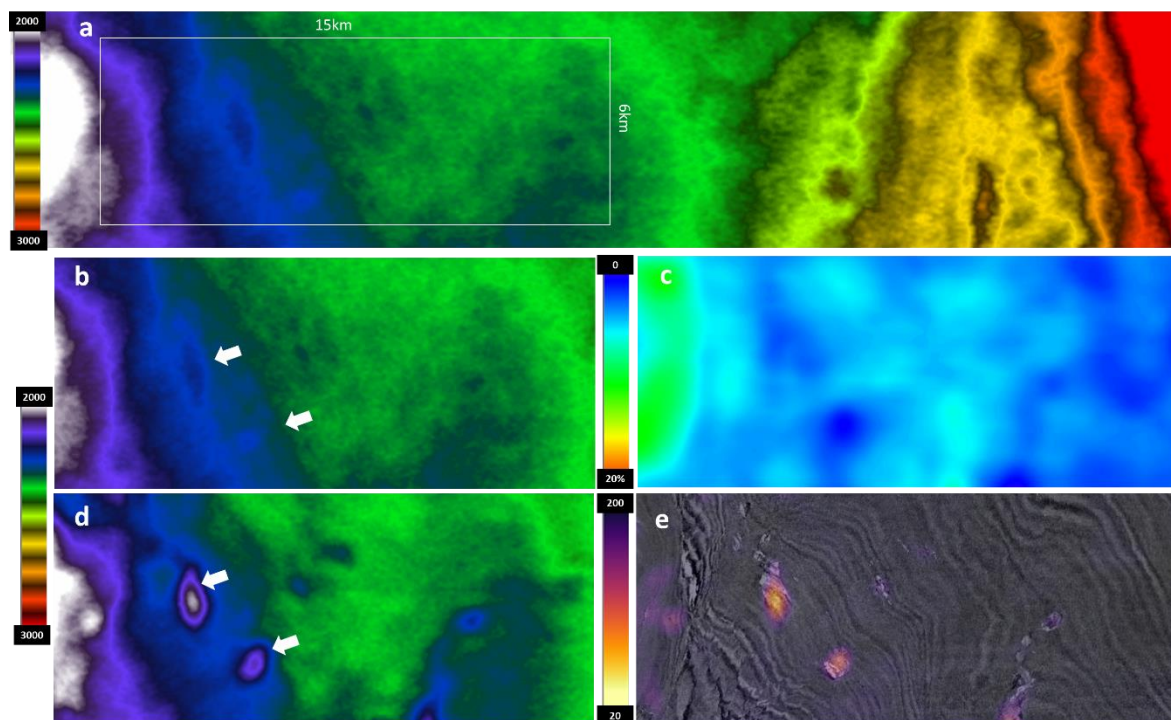


**Figure 1:** Time slice top left and right present PSTM versus PSDM converted back to time. On this shallow time slice thin gas pocket and faulting are better focused leading to a net image. Bottom left and right present same result on a deeper slice crossing the Alta structure. Complex faulting below the Permian can now be well tracked and understood.

## Tomographic velocity model building

Thanks to FWI, depth velocity model building can start at the very beginning of an imaging project, as it only requires raw shot gathers as input. Although, mainly driven by diving wave, FWI may struggle to decouple vertical velocity and anisotropic parameters. Consequently, this methodology will provide a poor depth calibration and gather flatness when the anisotropic law is not properly defined. FWI then requires good anisotropic parameters as input in order to both minimize the data difference and flatten common image gathers (CIG). For the Greater Castberg, having a strong lateral anisotropic variability, it is important to first derive a proper anisotropic field prior starting the FWI update. A fast-track processing was therefore done to produce pre-stack CIG so providing kinematic information. As previously mentioned, pre-processing steps, such as denoising or demultiple will also benefit from this unique acquisition design to give clean CIG for RMO picking. Available proper CIGs were also of great use to QC early velocity estimation result.

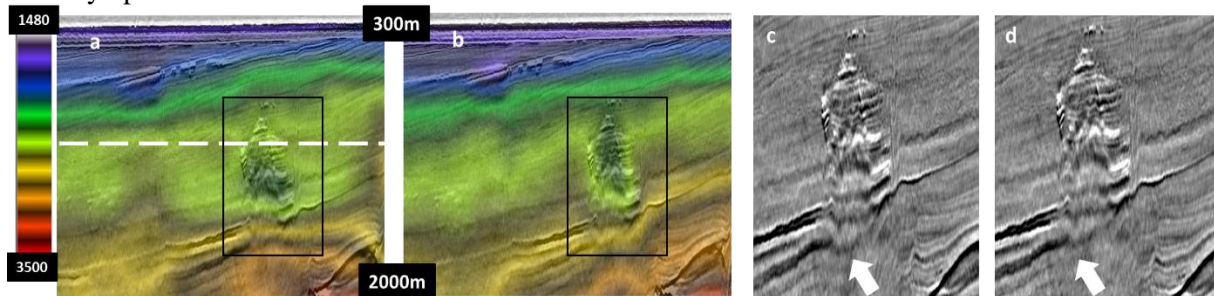
For the RMO, being able to pick the full incidence angle from the water bottom reflection combined with the dual azimuth information leads to robust curvature information. Obtained RMO, coupled with well miss-ties and First Break information allows the vertical and horizontal components of velocity to be separated. The quality of the data allowed us to get the full benefit from recent developments in the tomographic inversion. In particular, a dense, high-quality RMO picking was performed. It honored the events curvature in the offset domain, as well as the offset-dependent structural dip variations in the image domain, in a consistent manner. A newly developed “Enhanced High Definition” (EHD) tomography was used to transform this picked information into a velocity field by using fine update grids and a very small level of constraints in the tomographic inversion. No geological a priori information was used in the inversion in order to “let the data speak” as much as possible. It results in a velocity model with an impressive lateral resolution that made geological details clearly visible (Figure 2a, b, c) and allows to flatten CIGs. This derived tomography velocity field still faces limits in velocity update in case of strong velocity contrast, where RMO’s information are limited. As numerous shallow gas pockets exist within the Greater Castberg survey area, the need for FWI to update the velocity becomes obvious at that stage (Figure 2d, e).



**Figure 2:** 900m depth slice of Castberg velocity (a, b) and Epsilon (c) field for EHD tomography and joint Velocity(d)/Q(e) update with FWI at 7Hz. Continuity in resolution between tomography and FWI is well visible while FWI velocity allows to better recover low velocity gas pockets (white arrows).

## Full Waveform Inversion

Deep cable depth and a powerful front source provided clean low frequency data to start inversion at 3 Hz and currently ending at 7Hz. With a maximum offset of 8 km thanks to the front source, the estimated diving wave penetration is greater than 2 km, which allows diving wave to update velocity below the gas pocket (Figure 3). By using an optimal transport cost function in FWI (Poncet et al., 2018), the shot-gather data mute can be opened wide to include more data from the initial iterations without risking cycle skipping. This will allow a deeper and more stable velocity update. In such a geological context where both FWI and tomography are mandatory in order to obtain a correct velocity field for imaging, proper anisotropy (Epsilon) derived by joint-tomography is necessary to conceal above mentioned methods. Good imaging brought by FWI will then also lead to a flat event on the CIG. Information from diving waves allows to fully recover gas pocket velocity and then efficiently enhance tomographic velocity update.



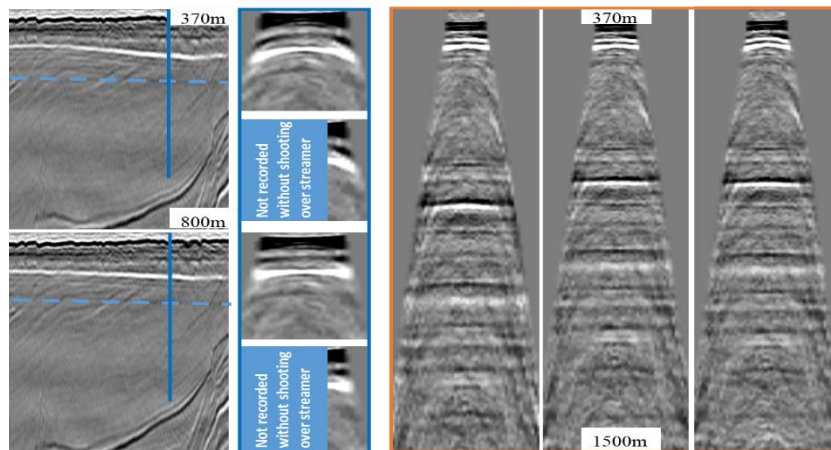
**Figure 3:** Benefits of long offset is illustrated with a velocity only FWI (5Hz for current comparison) to well highlight gas chimney definition. Stack section (a) present FWI velocity obtained with a maximum offset of 3.5 km (using only the Top Source) while (b) shows update with 8km offsets. With a limited penetration depth (white dotted line) for Top Source, FWI update relies more on reflection to update deep part and then lead to more reflectivity details but unstable velocity. Panel c and d shows migrated section using FWI with maximum offset 3.5km and 8km. Event below gas chimney start to be more continuous (white arrow).

Greater Castberg region contains a thin layer between the water bottom and the Base Quaternary where velocity variation can be important. A tomographic velocity update using only RMO information is not able to fully flatten the Base Quaternary without additional constraints. The benefits of FWI to update the velocity just below the water shows on image a simplification of the Base Quaternary structure and it is confirmed when checking the CIG curvature, which is unique to source over the streamer acquisition for this relatively shallow depth (Figure 4 blue panel). These FWI results need to consider Delta to accurately fit the wells markers and Epsilon to ensure flat CIG (Figure 4 orange panel).

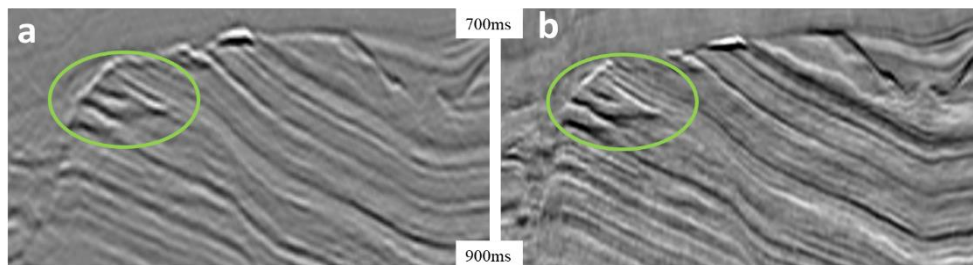
The good correction of the Quaternary layer is then important to solve the full Tertiary layer present underneath and containing most of the primary hydrocarbon targets. A way to confirm the correct imaged Tertiary structure is to refer to water-hydrocarbon contact which aims to be flat. The observed flat spot (Figure 5) appears more visible and well horizontal after final imaging. When compared with available vintage in the area (2008 conventional towed streamer acquisition), the benefits of the source-over-streamer for both pre-processing and velocity model building are well visible.

## Conclusion:

The source-over-streamer configuration has been designed to improve pre-processing of the seismic data leading to high-resolution imaging. It also leads to better RMO estimation, unique in its high quality and density. By adding a front source to the original design, long offset information is now available for FWI velocity update. The combination of the reflection information from the clean CIG and the diving wave from the long offset allows a high-resolution anisotropic model to be obtained. The final seismic section not only shows high-resolution benefits but also accurate depth positioning and proper imaging of complex geological structures.



**Figure 4:** Top and bottom left PSDM with tomographic and FWI velocity update. Base Quaternary, white event above the dotted line, is well flattened with the FWI velocity and corresponding CIGs are flattened. Orange panel shows CIG from isotropic (left), anisotropic (middle) FWI and anisotropic tomography (right) with the change in depth to properly match the available wells.



**Figure 5:** Vintage final image (a) is compared with very fast track PSDM combining TTI-tomography and FWI (b). Current image shows strong uplift in term of details and shallow flat spot (green circle) is now well aligned and its termination on both side is well visible.

## Acknowledgements

Authors would like to thanks Thibaut Allemand for his strong implication on EHD tomography development, Lundin and CGG Multi-client & New Ventures for permission to show data examples.

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