Tu_P01_02

A Deblending, Demultiple and High-Resolution Velocity Model Building Workflow Across the Senja Ridge

S. Stokes[1]*, D. Manns[1], M. Romanenko[1], B. Kjølhamar[1], R. Myklebust[1], E. Henden[1]

[1] TGS

Summary

Triple-source, continuous-recording acquisition is used to acquire a modern, high density 3D survey across the Senja Ridge and the surrounding salt provinces of the Tromsø and Sørvenstsnaget basins, in the Western margin of the Norwegian Barents Sea.
A robust imaging workflow is developed and presented, combining deblending technology with extensive demultiple methodology to precondition the data for velocity model building, utilising Full Waveform Inversion and high-resolution image guided tomography.
The final migrated image delivers a significant uplift in imaging across the area, with the advanced velocity model building techniques adding confidence to the positioning of events both within the Senja Ridge and the surrounding salt basins.

Introduction

Acquired in 2017, the Carlsen 3D survey consists of 5787 km^2 of narrow-azimuth 3D streamer data over the structurally complex Senja Ridge in the Norwegian Barents Sea (Figure 1). Located between the Tromsø and Sørvenstsnaget basins, the Senja Ridge is a structural high dating from late Palaeozoic times. The region experienced multiple rifting events during the late Cretaceous and Tertiary which have further modified the ridge and surrounding basins (Faleide et al. 2008).

The northern part of the ridge is defined by a three-part gravity anomaly, massive salt diapirs are found adjacent to pre-Jurassic basement horsts, in turn surrounded by onlapping Cretaceous and Palaeocene sediments. Towards the south of the ridge, sedimentary structures are observed alongside rotated fault blocks. Shallow gas anomalies are observed across the survey.

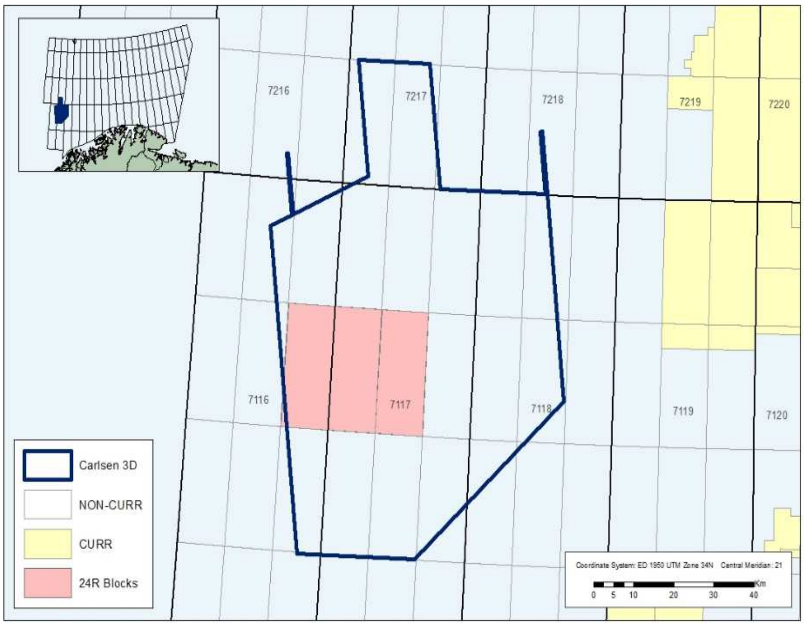

Figure 1 *Location map of the Carlsen 3D survey.*

The acquisition utilised a triple-source continuous-recording methodology to acquire a dense acquisition grid of 6.25 m x 12.5 m and 10 s record length. The survey was acquired within a single season.

The processing sequence is developed to address the already well-documented processing challenges within the Barents Sea (Hardwick et al. 2014) as well as the added complication the blended acquisition. We discuss the key processing stages.

Deblending

Triple-source seismic acquisition enables data to be acquired on a denser crossline grid, whilst simultaneously maintaining the subsurface footprint coverage. The downside to this is that to maintain fold of coverage in the inline direction, overlapping source energy is recorded within the 10 s record length, this relationship is presented schematically in Figure 2. For any given shot record, we refer to the energy originating at T=0 as S2. Energy from the previous shotpoint location coming through T=0, referred to as S1, and the subsequent shot, referred to as S3, appearing at approximately T=5 s is also recorded.

The methodology used to deblend the 3D survey is described in full by Baldock et al. (2018) and is only summarised here. The key step in attenuating the blended energy is to utilise the random nature of the S3 energy in the common-receiver domain when aligned to the S2 source time and *vice versa*.

Initial separation is performed using tau-*p* transforms in the common-receiver domain with the data aligned to S3 arrival time, residual energy is further attenuated using multidomain denoise (Masoomzadeh et al. 2017**)** methodology in both the 2D CMP and common-receiver domains.

To facilitate the removal of the S3 energy, a Gaussian distributed shotpoint (GDSP) location scheme is implemented to build a random distribution in shotpoint locations into the preplot map. This combines with the natural variation in shot timing caused by factors such as changes in boat speed to further randomise the arrival time of S3.

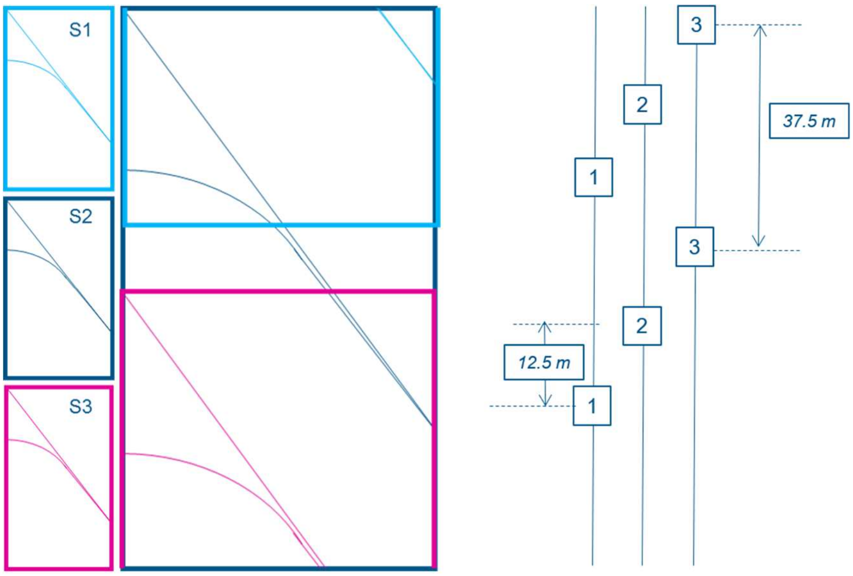

Figure 2 *Definition of seismic sources within a triple source acquisition (After Baldock et al. 2018)*

The deblending results are presented in Figure 3. Figure 3a is an inline stack aligned to S2-time prior to deblending, S3 energy can be seen dominating the stack section. In Figure 3b the previously masked primary energy is revealed with minimal residual contamination of S3 energy.

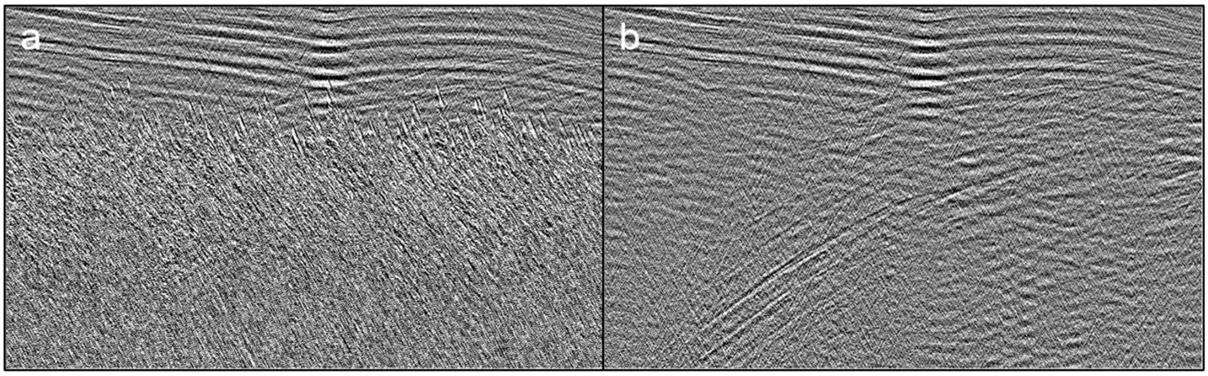

Figure 3 *(a) Stack section before deblending. (b) stack section following removal of S3 energy*

SRME / SWME

Barents Sea surveys are typically characterised by strong free-surface multiple trends that dominate the section, the underlying primary energy is typically weak in amplitude when compared to the multiples (Figure 4a). This amplitude difference adds complexity to the adaptive subtraction step as leakage of primary energy is very difficult to identify.

An iterative modelling approach is used to address this problem, with each iteration targeting a specific order of multiple, multidomain adaptive-subtraction [MDS] is used to subtract the free-surface multiple energy from the dataset.

The first iteration of multiple suppression utilises a three-model approach. Shallow-water multiple elimination is used to generate source and receiver-side models, a surface-related multiple-elimination model is also predicted from the same input dataset. These models are simultaneously adapted to the input data using a least-squares algorithm (Figure 4b). Then the resulting adapted multiple model is fed into a pass of MDS providing the first iteration subtraction result.

The first iteration is successful in attenuating free-surface multiples; however, some multiple energy remains that requires additional suppression (Figure 4c). A second, cascaded pass of SRME is applied, generating a multiple model free of the higher-order simple water-column multiples (Figure 4e) allowing the MDS to target the residual, lower amplitude, free-surface multiple energy (Figure 4f).

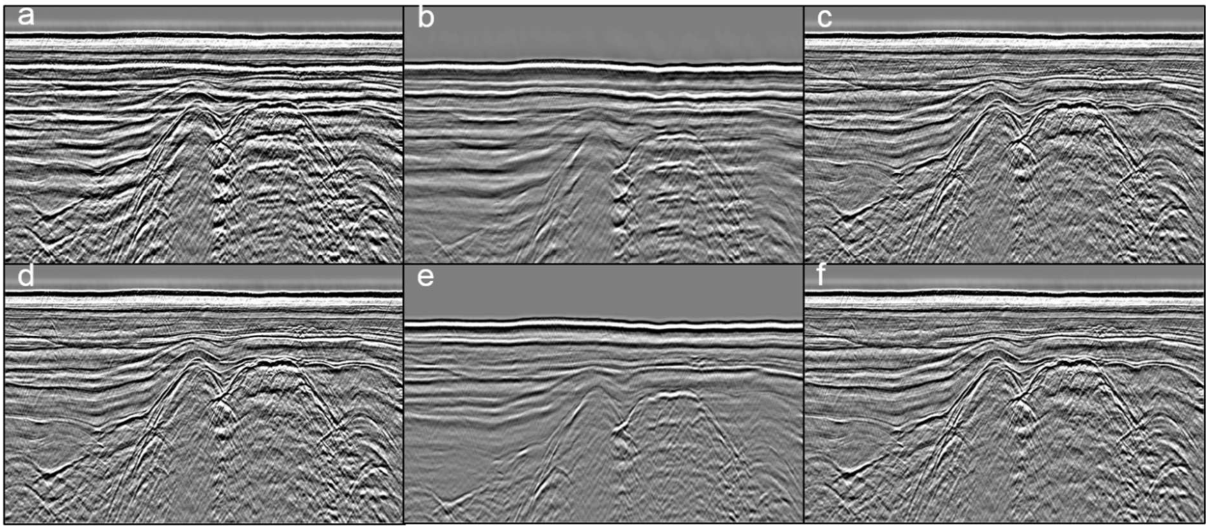

Figure 4 *(a) Input stack over across the Senja Ridge. (b) Iteration 1 SWME + SRME model. (c&d) Iteration 1 MDS result. (e) Iteration 2 SRME model. (f) Iteration 2 MDS result.*

Velocity model building

High-resolution image-guided tomography is used in a top-down, layer-stripping approach. The initial iteration is run using a smoothed velocity model derived from the PSTM migration velocity field, this update is calibrated to the three well locations present within the survey area. Delta and epsilon anisotropy parameters are estimated at the three well locations and extrapolated across the entire survey using the interpreted base-Pliocene and base-Cenozoic horizons as constraints. All subsequent migrations for tomographic model building are run as TTI.

The initial tomography updates are concentrated in the postsalt sediments in the shallow, these updates are further constrained by masking out the Senja Ridge and basement to prevent the high velocities leaking into the sedimentary velocity trend. Salt interpretation, salt flood and base of salt interpretation are undertaken where required, basement velocities are stamped in followed by a further 2 iterations of tomography to update the velocity profiles in the deep section.

The shallow gas clouds that are identified across the survey introduce potential distortions into the underlying sediments. Diving-wave FWI is used to build a detailed velocity model of these features along with other shallow-velocity anomalies that will introduce distortions into the final migrated image if not correctly resolved. The calibrated velocity model is used as the starting point for the FWI updates.

Due to the sparse well control within the survey area, the first step in the FWI workflow is to invert for epsilon. is subsequently converted to delta using a ratio derived from the three well locations. Velocity updates are then run based upon this anisotropy field, updating to a maximum frequency of 12 Hz.

The final Kirchhoff depth migration results, showing a transect across the Senja Ridge, are presented in Figure 5.

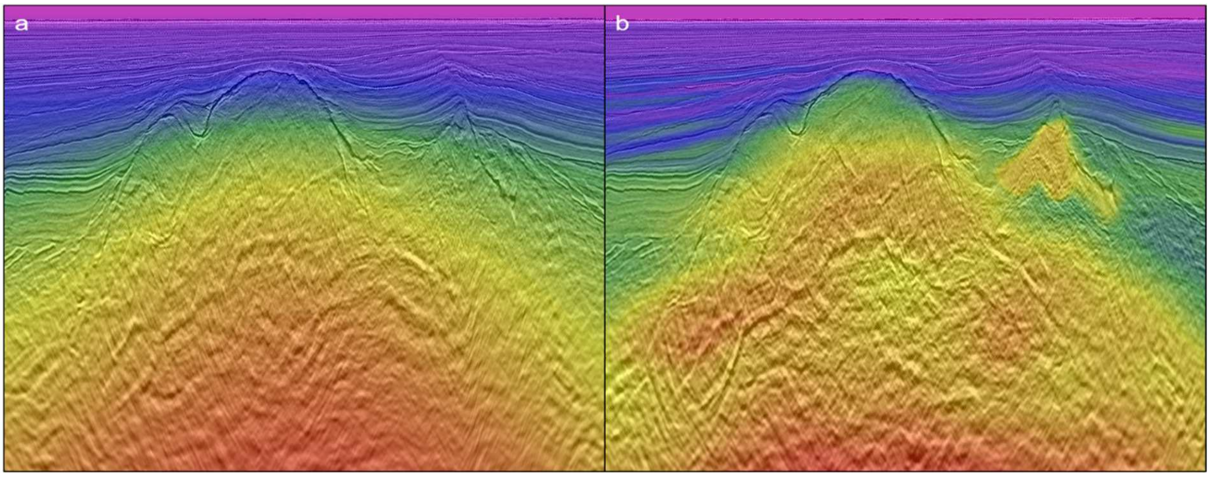

Figure 5 *(a) PSTM section stretched to depth over the Senja Ridge, velocity overlay is the migration velocity converted to Zint. (b) PSDM section over the same area with the corresponding Zint overlay. Structure within the Senja Ridge, and adjacent previously incorrectly imaged salt bodies, are resolved through PSDM processing.*

Conclusions

Triple-source, continuous-recording acquisition combined with deblending technology has resulted in a modern 3D dataset, acquired within a single acquisition season in the Norwegian Barents Sea. An extensive SWME / SRME demultiple scheme is combined with multi domain adaptive subtraction technology to address the strong free-surface multiple component that is present in Barents Sea data.

FWI and high-resolution tomographic model building add confidence to the positioning of events both within the Senja Ridge and in the surrounding salt provinces, resulting in a significant imaging uplift across the survey area.

Acknowledgements

The Authors would like to thank TGS for permission to show the data and the processing team, particularly Gboyega Adeloye and Matt Hart, for their hard work on the project. We would also like to thank Connie VanSchuyver and Simon Baldock for reviewing this paper.

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