Efficient Suppression of Multiples in the Valemon-Kvitebørn Reprocessing and Imaging Project

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Summary

We discuss an efficient multiple suppression workflow applied to the processing of seismic data covering the Valemon and Kvitebjørn fields. Both fields are deep and structurally complex. An interference of very strong multiples, mainly water-layer peg-legs from a hard and shallow water-bottom, with much weaker and broken up reservoir horizons makes successful multiple removal quite challenging. In the project we used a combination of 3D WEREM for the prediction and removal of water-layer multiples together with 3D SRME to both predict and suppress the remaining free-surface multiples. A consistency between the multiple prediction and the following adaptive subtraction in all the steps applied, has been a major factor for the overall success in de-multiple without harming the primaries. Compared with earlier versions, there are significant improvements in the final image quality. In the reservoir zone, the faults, the primaries and the dips of the primaries are significantly better defined, which is vital for both confident reservoir zone interpretation and further well planning.
Introduction

Valemon and Kvitebjørn are located at the Huldra-Kvitebjørn stepover related to the Viking Graben. Due to the location both fields are deep; the reservoir is at 4000 m and deeper, and structurally complex. Both fields are HPHT, gas-condensate fields producing mainly from Upper Brent. Due to the structural complexity, accurate seismic imaging is very important for well placement and drainage strategy. The input gathers for this project are P-UP from a GeoStreamer data set, ST13001, provided by PGS in 2013. The main objective of the project is to improve the definition of both primaries and faults in the BCU-Lomvi (Triassic) interval, Figure 1. There are many seismic challenges in processing and imaging in this area. The most relevant challenge for this work remaining from all previous efforts is interference of strong surface multiples with much weaker and broken up reservoir horizons. The main purpose of this paper is to demonstrate efficient suppression of these multiples, especially suppression of water-layer multiples and peg-legs.

![Figure 1](image-url) An example of a depth to time converted section from a previous project. The main objective of current work is improved imaging for structural interpretation of the reservoir zone. Efficient suppression of water-layer peg-legs from BCU and above is essential.

Removal of multiples

The input data are contaminated by very strong multiples and peg-legs from a hard sea-floor, see Figure 2A and 3A. A combination of a shallow water-bottom together with a complex deep target makes it practically impossible to remove these multiples using velocity discrimination, at least in the reservoir zone and at near offsets. Therefore, for these data, successful multiple removal based on deconvolution, wave-equation approach and or SRME is crucial for accurate velocity model building and imaging. The ‘art’ of efficient de-multiple using such approaches is not just accurate prediction of multiples, but a consistency between multiple prediction with following adaptive subtraction: one will not achieve an optimal de-multiple if predicted multiples of different orders interfere and require different ‘amplitude’ corrections. In the project, we used a standard combination of shallow water-bottom de-multiple by 3D WE (wave-equation) approach with following 3D SRME. For principles of WE approach and SRME see, for example, Berryhill and Kim (1986), Wiggins (1988) and Berkhout and Verschuur (1997). In the project, we used a fast WE approach called WEREM, based on Lokshtanov (2000, 2005) for 2D and 3D versions respectively. In this work he showed that independent of the hardness of the sea-floor or the thickness of the water layer, suppression of all water-layer multiples and peg-legs requires three prediction terms – prediction from the receiver side, prediction from the source side (after muting of primary reflection from the sea-floor) and prediction from the source-side after prediction from the receiver-side (a second-order term in deconvolution). The prediction of multiples accounts for known sea-floor geometry, but neglects sea-floor reflectivity. Predicted multiples are simultaneously suppressed from the input 2D CMP tau-p gathers by multi-channel and multi-dimensional least square adaptive subtraction in one or a few time windows. For each prediction term and for each slowness p (and for each time window), the adaptive filters account for local angle-dependent reflection coefficients from the water bottom and for small phase shifts due to imperfect knowledge of the water-bottom
geometry. Working in the Radon domain allows us to perform additional multiple removal by \textit{tau-p} muting and makes it simple to mute direct arrivals prior to multiple prediction. The main two steps - WE prediction and adaptive subtraction - are consistent, since each prediction term contains multiples, which require the same amplitude correction. Such consistency is full when water-bottom reflectivity slowly varies along the sea-floor. The extension of the method for the case of fast variation of water-bottom reflectivity is considered in Lokshtanov (2012). Fast prediction of the required multiple terms also assumes slow variations of sea-floor geometry, but arbitrary 2D/3D structure below it. Note that such cases is typical for the majority of data from the NCS. In WEREM, for each CMP and for each $p$ the result of multiple prediction is simply obtained by a sum of time delayed input traces with the same $p$ from the neighbour CMPs. The time delay depends on $p$, local sea-floor depth and differences in coordinates between output CMP and neighbour input CMPs. In case of 2D WEREM, input CMPs are along the same CMP line as output CMP. In 3D case, input CMPs are along neighbor CMP lines. For the 3D case, the receiver-side prediction is exact, while 3D source-side prediction (for current quasi 3D marine acquisition with poor sampling between shots in the cross-line direction) requires an additional assumption. We assume that cross-line slowness from the source side is the same as from the receiver side (the same azimuth for 1D structures). This assumption also gives an immediate formalism to mix data with flip flop shooting (Lokshtanov, 2005).

![Figure 2](image.png)

**Results**

Figure 2A shows a section for the Valemon area for input data after Kirchhoff 3D PSDM, depth to time conversion and stacking. The section is strongly contaminated by water-layer multiples and peg-legs. Figure 2B shows 3D PSDM result for data after 3D WEREM. The method proved to be very efficient in removing water-layer multiples while preserving primaries. Note that for a ‘shallow’ part above BCU, the results of 2D and 3D WEREM are practically the same. However, in the target, the 3D version leads to better de-multiple of first order water-layer peg-legs from BCU. Therefore, the decision was to use the 3D version, despite the fact, that it is at least one order more time consuming than the super-fast 2D version. Also note that the ‘prediction’ part of the adaptive filters used is quite long, about 120 msec, so that the ‘water-bottom’ reflection operator also includes strong reflector from gas sands just below the sea-bed. Tests showed that this is a better strategy than postponing the removal of the free-surface multiples created by these reflectors to following SRME (at least when only one iteration of 3D SRMP has been used). Of course, using a long operator in adaptive subtraction requires significant ‘lateral
averaging’ (multi-channel adaptive subtraction in a sliding window over several CMPs) to minimize least-square artifacts and to improve discrimination between primaries and multiples. After WEREM, we muted the primary reflection from the ‘water-bottom’ (according to the length of the adaptive subtraction operator used; another advantage of implementing WEREM in tau-p domain, where such mute is straightforward) and used the result as input for 3D SRMP to predict remaining free-surface multiples. During the prediction, required missing traces have been reconstructed by NMO repositioning of the ‘closest’ traces (Kurin et. al., 2006; Moore and Dragoset, 2008). Finally, the results of 3D SRMP have been adaptively subtracted from the results of 3D WEREM. Figure 2C shows 3D PSDM result after 3D SRME. It significantly ‘cleaned up’ the section, especially in the deeper part. Figure 2D shows the difference between input image at Figure 2A and final result after de-multiple at Figure 2C. Note not only the successful removal of multiples, but also no obvious leakage of primaries into the difference – multiples removed. Also, since plane-wave decomposition (forward and inverse point-source Radon transform) are present in the WEREM workflow, the potential distortions of the signal from these transforms should be present in the difference. No evidence for such distortions in the difference 2D. Figure 3 shows similar results of 3D PSDM as in Figure 1, but for Kvitebjørn test line. The results shown are for a constant offset of 1000 meters. Though some weak residuals of strongly dipping multiples are present in a very shallow part of the final result in 3C, the overall quality of the de-multiple is excellent.

QC of de-multiple steps by 3D PSDM has been performed with the preliminary velocity model. An example of the depth to time converted section and CIGs after final migration and post-migration processing are shown in Figure 4. Note that at around 4 sec. the events at gathers are practically horizontal up to the maximum offset of 6200 meters. The description of used velocity model building approach will be given in a separate paper. Here we just mention that the main elements include a combination of migration velocity analysis to reconstruct travel-times at datum level with fast and robust nonlinear velocity inversion. Velocity inversion is in turn a combination of layer stripping approach with global tomography using parameterization of velocities by ‘conformal’ layers and with well-tie to invert for anisotropic parameters, Figure 4. The most important steps of post-migration processing include: parabolic Radon de-multiple; adaptive spectral balancing; compensation for illumination, acquisition geometry and approximations in the migration kernel; removal of acquisition footprints.
Conclusions

Compared with earlier versions, there are significant improvements in image quality, Figure 6. For reservoir interpretation and well planning the main contribution is that the primaries and the dips of primaries are much better defined than from the previous projects. The fault mapping is easier and with higher confidence. Very efficient multiple removal without harming primaries by WEREM with following SRME is regarded as the main contributor to the overall success of the project.

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