High-fidelity Velocity Model Building and Imaging Using Reflections, Refractions and Multiples Arrivals from Dual-sensor Streamer Data

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We demonstrate the success of combining wavelet shift tomography, full waveform inversion (FWI) and separated wavefield imaging (SWIM) for Pre-Stack Depth Migration (PSDM) velocity model building and imaging. FWI utilizes the low frequency refraction arrivals, and SWIM exploits the greater illumination in the shallow section inherent in the multiple raypaths. The data under investigation were acquired in 2009 using dual-sensor cables over the Utsira High area offshore Norway. The 1600km^2 surface seismic survey covers the largest exploration discovery offshore Norway in the last 30 years. Relatively thin target sands are situated below a complex chalk layer and span hundreds of square kilometers. The complex geology in the area leads to a large uncertainty in estimating the associated oil reserves. Currently the reserve estimates vary between 1.7 and 3.3 billion barrels; the aim of this study, a research collaboration between PGS and Lundin Norway, was to achieve more accurate depth predictions and better imaging of the target sands.

A legacy PSDM velocity model was used as a starting point; however, due to the shallow water depth of approx. 100m in this area, conventional reflection tomography had failed to produce a shallow overburden model with sufficient accuracy to avoid cycle skipping in refraction FWI. The velocity model was updated using wavelet shift tomography, which inverts densely picked residuals measured in a 3D sense, with a focus on anisotropy for the shallow overburden in order to better match observed and modeled refractions. FWI updates were subsequently able to resolve high resolution velocity variations associated with channels, pockmarks and gas pockets in the shallow overburden.

Following the wavelet shift tomography and FWI velocity model building, gathers from SWIM were generated using up- and down-going wavefield estimates uniquely provided by dual-sensor data. These SWIM image gathers were used to validate the longer wavelength features not seen by FWI. The additional illumination provided by imaging both primary and multiple wavefields provides a high resolution shallow volume and angle gathers free of the acquisition footprint. This was of particular importance since a shallow wedge is covering large parts of the field. The long wavelength velocity variations associated with this wedge structure have a significant impact on the vertical position of the target sands in respect to the oil water contact. For the deeper part of the overburden, particularly the chalk layer and the target zone, high resolution wavelet shift tomography was applied. Significant improvements were observed in the quality of the final high resolution subsurface image compared to the legacy PSDM data, especially for the chalk layer and the target sands.

The study illustrates how reflection, refraction, and multiple arrivals from dual-sensor data can contribute towards high-fidelity model building and imaging. Resolution of the complex shallow overburden leads to more accurate positioning and depth predictions for the reservoir, directly impacting estimation of reserves.