Petrophysical Seismic Inversion Applied to the Troll Field.
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Summary

We present an application of petrophysical seismic inversion, a method driven by petro-elastic models, updating a fine-scale geological model in depth to make it fully compatible with pre-stack seismic measurements on a part of the Troll Field Central province, in the North Sea. The results are being evaluated for infill drilling and for a future 4D inversion to determine the remaining oil in the thin oil leg.

Introduction

This project is a pilot study to apply this new methodology (Bornard et al., 2005) on an offshore sandstone reservoir characterised in an existing fine-scale geamodel, with well-understood geological setting and good quality seismic data. It involved the Troll asset team and R&D groups from Hydro and CGG.

On the Troll West field, permeability is the main petrophysical variable that controls the oil production behaviour. In the geo-model and for well planning purposes the sands in the Sognefjord formation are divided into two categories, namely Clean-sands and Micaceous-sands corresponding to different sorting and leading to different porosity distributions. There is a large contrast in permeability between the good and the poor sands in the reservoir. Thus the drainage patterns are controlled by the sand quality along the well branches. An updated petrophysical model using the seismic could improve the geo-steering of well branches during drilling in the thin oil leg.

Petrophysical Seismic Inversion: Methodology

Unlike traditional seismic inversion techniques that solve for elastic properties in time, the Petrophysical Seismic Inversion (PetroSI) operates on rock properties in depth. The PetroSI workflow is illustrated in Figure 1. We start from an initial fine-scale geosmodel defined from a 3-D stratigraphic grid in depth (left). A Petro-Elastic Model (PEM) is applied to calculate elastic properties in each cell of the geosmodel from stored values of porosity, rock type and saturations (middle).

Figure 1: Petrophysical Seismic Inversion workflow.

Angle-dependent reflectivity series are calculated from the elastic properties through the Zoeppritz equation at each trace location. The reflection coefficient series are then converted from depth to time using the velocities stored in the geosmodel. Angle-dependent 3-D synthetics are finally generated by wavelet convolution (top-right in Figure 1). Perturbations of the properties of the geosmodel are introduced using a simulated annealing algorithm to optimise the degree of match between the synthetic and the real angle stacks. After convergence, the final geosmodel honours the observed seismic amplitudes, is consistent with the user-specified PEM and integrates inversion-based velocities that ensure coherence between the depth and time domains. It should be noted that changes in the initial model such as the small-scale distribution of rock type, or the modification of the PEM would lead to different solutions. The final models then represent alternative solutions consistent with the seismic data.

PEM Calibration

This step is critical. It reconciles different static measurements (cores, logs and seismic) obtained at different scales and different domains (depth and TWTTime). The PEM is based on the Rock Physics Template obtained after comprehensive studies by Hydro (Avseth et al., 2005). The use of the petro-elastic model establishes the necessary link between \( V_p \), \( V_s \) and \( \rho \).
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On selected calibration wells, like in Figure 2, the porosity, saturation and rock-type information are used to predict $V_P$, $V_S$ and $\rho$ through forward modelling. This information, in blue in Figure 2, is compared to log data (compressional and shear sonic and density logs in black). The forward modelled $V_P$ is also used to define the time-depth relationship, controlling the two axes on the left. Synthetics are computed from angle dependent reflectivity series and compared with the corresponding seismic angle stacks.

Data Pre-conditioning and QC

The initial model includes the geomodel in the Sognefjord formation at reservoir scale and an overburden model needed to compute the seismic response.

The provided geomodel was constructed from well information and the knowledge of depositional environment: East-West prograding sand lobes with sorting within the lobes controlling the porosity distribution. The synthetic response computed from the initial model does not match the observed seismic. The 2003 seismic vintage is used in the study, while production of the thin oil layer beneath the huge gas cap started in 1999, with an extensive drilling program of 110 horizontal wells.

In Figure 3, the maximum of cross correlation in a moving window between synthetic and observed seismic indicates where the match is good (red colour). In these areas minor changes in time and amplitude during inversion will ensure a good fit. In other areas (green and blue colours), larger updating of the geomodel will be needed during the inversion process. Detailed analysis of the seismic data in the reservoir area led to a pre-conditioning processing sequence, including multiple attenuation and high-resolution velocity analysis to reduce residual NMO problems but also geostatistical filtering on the near angle stacks for reduction of noise and residual multiples present in these sub-stacks. This pre-conditioning is critical to increase the “Zoeppritz-compliance” of the AVA behaviour (Coléou et al., 2005) and to ensure that the seismic data is suitable for inversion.

Residuals from inversion, i.e. the misfit between the seismic measurements and the synthetic response, are monitored during the different phases of the process; the pre-conditioning of the seismic data, the wavelet extraction, the calibration and the inversion trials. Wavelet scaling through the various angles is also a critical step and specific residual analysis and QC procedures are applied to ensure optimal match of the AVA behaviour. In Figure 4, such a QC is displayed, comparing for each angle stack the match between the modelled and observed seismic traces as well as the correlation between the residuals and the synthetic traces, indicator of potential wavelet scaling problems.
Results

The PetroSI result for an inline is shown in Figure 5, together with the input model and the petro-elastic relations linking velocity and porosity, comparing linear trends (dashed red and light blue) with Hashin Strikman model for water bearing sands (yellow).

Figure 5: The input porosity and saturation model (top), petro-elastic relation and the final result of the inversion (bottom).

The initial primary target is the porosity distribution in the gas zone above the contract as there is a mismatch between the saturations in the geomodel and the real ones at the time of the seismic acquisition. The inversion has clearly changed the input model considerably, but in a geologically reasonable way.

One of the main challenges on the Troll field is to remove the imprint of the flat spot on the porosity model. In Figure 5, there is still an indication of the HC-contact in the porosity model. This is probably due to the fact that modelling of the HC contact is not fully correct, as a significant amount of oil has been produced prior to the acquisition of the 2003 seismic vintage. This is consistent with the fact that the HC-contact has been difficult to match in the wavelet extraction. The positive part is that the seismic bears such detailed information above the actual saturation distribution around the HC contact.

Figure 6 shows the cross correlation between a typical well (which was not used in the inversion) and the inverted data. Comparison is made with the porosity log (cross plot on the lower right) and the effect of upsampling from log to the scale of the geomodel is shown on the cross plot on the lower left of the figure.

Although it is always difficult to plot log data versus inverted data due to the difference in resolution, the cross plot of the PetroSI versus well log data is very good. Note that this well was not part of the inversion process.

Analysis of the impact of the inversion can also be made on the porous volume within part of the reservoir.

Figure 6: Well log porosity (black), upscaled to the geomodel resolution (blue) and inverted result (green). The cross plot on the lower left shows the upsampling effect (black curve versus the blue curve). The cross plot on the lower right shows the Petro-elastic inversion result versus the well log measurements.

Figure 7: Porous volume in 3bc series (23 inverted layers) in the geomodel before inversion.
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In Figure 7 and Figure 8, the impact of the updating during inversion is shown. The analysis is made on a pore volume map over one the formations, the Clean-sand portion of the b formation of the 3 serie, developed in this area of the field, covering 45 km². Although the geomodel is already quite detailed, the seismic information increases the lateral resolution considerably.

Conclusions

A petro-elastic model is the link between rock properties and seismic data and should be at the core of seismic calibration. Through the Petrophysical Seismic Inversion, the fine-scale geomodel is reconciled with the seismic data, not by simply guiding the interpolation in between wells, but by guaranteeing the reproduction of the seismic amplitude for all angles after forward modelling. This updated geomodel is being evaluated for infill drilling and for a future 4D inversion to determine the remaining oil in the thin oil leg.

For the quantitative time-lapse simultaneous inversion in the next phase, it is particularly important to have the correct porosity model. Now the model response is directly optimised for reservoir property changes, in depth and at the scale of the flow units, the natural variables and domain to express the production-induced constraints. In the case of simultaneous pre-stack inversion, Zoeppritz equation dictates the behaviour of reflectivity across angles, for 4D inversion, production-induced constraints are necessary to control the simultaneous inversion of different seismic vintages. The constraints across the acquisition times come from the knowledge of the production-induced changes in the reservoir, usually expressed in terms of saturation and pressure changes and translated into elastic property constraints (Vp, Vs and ρ) through a petro-elastic model.

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References