Integrated 4D quantitative interpretation for assisted reservoir model updating

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Introduction

Time-lapse (4D) seismic has repeatedly demonstrated its value in impacting the reservoir model by directly measuring the state of the reservoir. The objective of its use in reservoir modeling is typically to relate the 4D seismic response with a given noise level to changes in reservoir properties, such as effective stress, saturations and reservoir geometry. The current work outlines the use of quantitative interpretation in a 4D context where information from different physical domains are integrated. Examples with real data illustrate the impact on reservoir model updating.

The use of 4D seismic data is typically performed in a semi-quantitative manner by identifying areas where the seismic reflectivity has changed due to production. This approach is relatively fast, and hence it is able to rapidly impact the update of the reservoir model. Yet, it is limited to primarily acoustic reflectivity changes, and hence it will suffer from an inherent non-uniqueness, as for instance an increase in acoustic impedance may be interpreted as an increase in water saturation and/or an increase in effective stress. If the quality of the 4D seismic data permits, its use can be extended to the amplitude versus offset (AVO) domain. Utilization of the 4D AVO signal may resolve, at least partly, this non-uniqueness, as effective stress changes respond differently to saturation changes in the pre-stack domain. The use of 4D AVO can be elevated even further with calibration to, and integration with other disciplines such as rock physics.

Method

The use of quantitative interpretation in a 4D pre-stack context involves the use of seismic 4D simultaneous AVO inversion. The inverse method applied here [Nasser et al. 2016] uses the Aki & Richards three-term reflectivity model in which multi-vintage pre-stack data are inverted simultaneously and directly for ratio changes in acoustic impedance, shear impedance and density. The motivation of its use is two-fold:

- The estimation of material properties as a part of the inversion process, as opposed to using interface properties, significantly improves the use of the potentially complex 4D seismic signal of a reservoir with complex architecture.
- The 4D seismic signal (AVO and time-shifts) is calibrated to and integrated with well data, and the estimated changes in elastic properties can be utilized in a rock physics inverse modeling context to yield, for instance, changes in saturation and effective stress.

The integration with rock physics provides changes in, for instance, saturations and stress, which both compare directly with the reservoir model.

Example

Among a number of cases, the following example is from the South Arne chalk field [Bruun et al. 2016] and illustrates the points above, where 4D quantitative interpretation has been used to assist in updating the reservoir model. Here, the motivation behind the application of a 4D quantitative interpretation approach is the desire to push the analysis of the 4D seismic data towards higher accuracy and detail. This is required for accurate placement of wells and optimal placement of hydraulic fractures.

The South Arne chalk field comprises of two units; the Upper Cretaceous Tor Formation and the Early Tertiary Ekofisk Formation. The porosity ranges from 20% to 45% and matrix permeability ranges from 0.1 to 8 mD with some natural fracture enhancement. Three vintages of 4D processed seismic data covering the South Arne field, one pre-production (1995), and two 4D surveys acquired in 2005 and 2011. Following extraction of the compaction associated 4D time-shifts, the relatively subtle amplitude changes are inverted simultaneously for changes in acoustic and shear impedance. An elastic rock physics model, which takes into account the varying degree (spatially and over production time) of compaction affecting the rock frame is estimated and used in inverse mode to estimate changes in water saturation from changes in the elastic properties.

Figure 1 illustrates the point above about the uplift in the usability of the 4D signal when going from an interface property (the sliding window RMS of the difference seismic) to a material property such as the change in water saturation. Figure 2 shows that there is a significant difference between the interface based NRMS map and the estimated water saturation change. The estimate is again similar in magnitude to the reservoir model response. Yet, it shows interesting differences such as significantly higher lateral resolution.

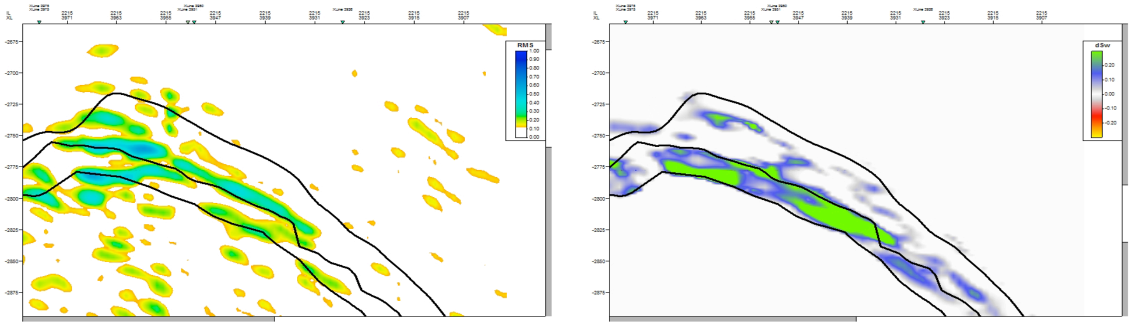

Figure 1 *Section through the main reservoir section. Interpreted horizons are overlaid. Left: Sliding window RMS of the difference seismic between 1995 and 2011. Right: Estimated change in water saturation from 1995 to 2011.*

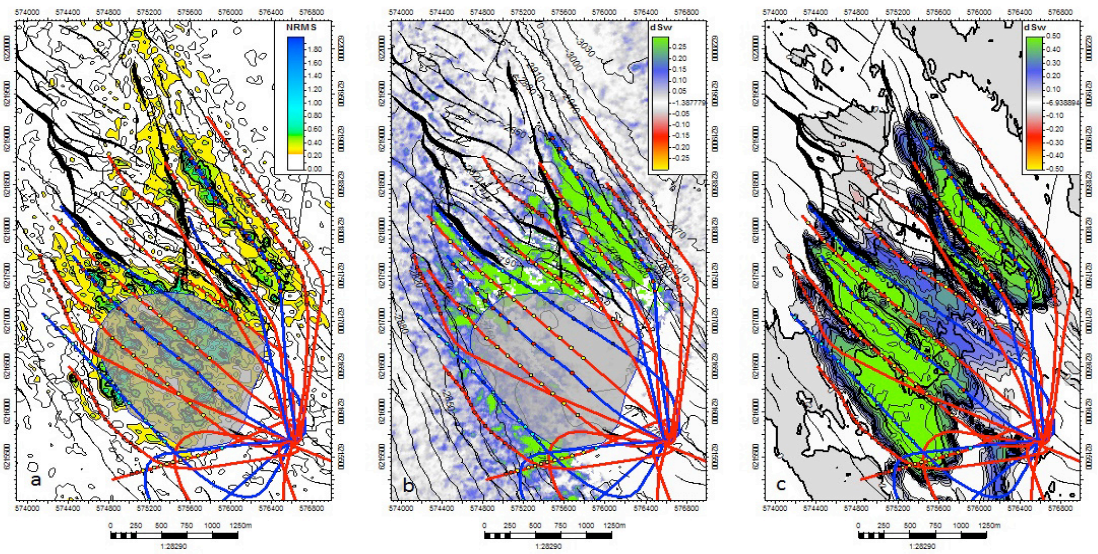

Figure 2 *Average maps of changes from 1995 to 2011 over the Tor main reservoir interval with wells overlaid. An area covered by a gas cloud is shown in grey. Left: NRMS of a full stack. Centre: Water saturation from 4D quantitative interpretation. Right: Water saturation from reservoir model.*

References

Nasser, M., Maguire D., Hansen, H. J., and Schiott, C. [2016] Prestack 3D and 4D seismic inversion for reservoir static and dynamic properties. The Leading Edge, 35(5), 415–420, 422–422.

Bruun, A., Rosengreen, M. K., Vejbæk, O. V., [2016] Integrated 4D quantitative interpretation on South Arne. The Biennial Geophysical Seminar 2016 “Integrated Geoscience” 14-16 March 2016, Kristiansand, Norway.