The National IOR Centre of Norway

Interpretation of 4D seismic for compacting reservoirs

Project 2.7.5

Project manager: Tuhin Bhakta

Other key personnel: Xiaodong Luo, Rolf Lorentzen, Kristian Fossum, Tor Harald Sandve, Geir Nævdal

Project duration: 2018-2021

Final Project Report

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1. Executive summary

This report summarises the research work on the project "Interpretation of 4D seismic for compacting reservoirs" and covers the period 2018-2021. The work was done in close co-operation with the large project "Data assimilation using 4D seismic data" and has resulted in several conference proceedings, in addition to presentations at conferences, workshops, and posters (see "Dissemination of results section" for more detail) and internal meetings/reports to ConocoPhillips. The work has been carried out in close collaboration with the provider of the field data (here ConocoPhillips).

The work had two focus areas. The first one was to improve and develop the petrophysical parameters inversion methodology using time-lapse seismic data. The interpretation of saturations and pressure changes from time-lapse seismic data is more complicated for compacting reservoirs as the changes (of pressure-saturations) are coupled with porosity change effects. Here, we focused on resolving the problems associated to these complications. To achieve this, we developed a stochastic method to interpret and decouple the compaction and production related effects using 4D seismic data. Here, an iterative ensemble smoother was used as inversion algorithm. The developed method further quantifies uncertainty in the estimated parameters. The developed method was tested on both synthetic data and on real field data provided by ConocoPhillips (Ekofisk field).

In the second part of our work, we focused on history matching for a compacting reservoir using 4D seismic data. We investigated and extended our recently developed assisted seismic history matching workflow (4DSHM) for compacting reservoir case. Here, the Ekofisk reservoir field was used as the case study. The method is based on sequential assimilation of production and seismic data, using ensemble-based Bayesian inference methods, and had successfully tested on the Norne sandstone reservoir.

2. Introduction and background

Quantitative usage of seismic data for petrophysical/ reservoir parameters inversion as well as in assisted history matching workflow remains a challenge to date. The problem arises due to improper petro-elastic model (PEM) to simulate forward seismic response, the inefficiency of handling the "big data" problem for seismic data, lack of adaptive localization algorithm that can be used for any kind of data/ observations, improper seismic inversion and many more. The issue becomes even more complicated in compacting reservoir scenarios due to the production related compaction.

Therefore, in this project, we aimed for better utilization of time-lapse seismic data for compacting reservoirs. However, the methods developed in this project would aid to use the 4D seismic information more efficiently and quantitatively in reservoir characterizations at any field on the NCS, regardless of compaction or not.

The work was developed through a collaboration with Xiaodong Luo (NORCE), Rolf Lorentzen (NORCE), Geir Nævdal (NORCE), Kristian Fossum (NORCE), Tor Harald Sandve (NORCE), Evgeny Tolstukhin (ConocoPhillips Norway), Carlos Pacheco (ConocoPhillips Norway).

3. Results

The results can be assorted into two main categories. They are petrophysical parameters inversion using seismic data and history matching performance by integrating seismic data. Here we explain them briefly.

3.1 Petrophysical parameters inversion – stochastic approach

In the project, we have implemented a stochastic method for petrophysical parameters. The framework uses iterative ensemble smoother as the inversion algorithm to estimate static as well as dynamic reservoir/ petrophysical parameters, such as saturations, pressure and /or porosity fields using seismic data. The algorithm is well known within the reservoir engineering community and has emerged as a significant history matching tool due to its derivative-free and non-intrusive features and better capacity of uncertainty quantification. The suggested approach is formulated as a Bayesian inversion problem where the prior is provided as an ensemble of pressure-saturation and porosity fields. The realizations of porosity and permeability fields of the prior model are generated using geostatistical methods and are further used in a reservoir simulator to obtain the realizations of pressure- saturations fields at the time of the seismic acquisitions. The pressure-saturation data and the porosities are then updated to account for the information available from seismic data (i.e. acoustic impedances, AVO etc) using an iterative ensemble smoother. The outcome is a new ensemble of pressure-saturation and porosity fields that honors the seismic data. Our results from both synthetic and real field showed that the suggested ensemble-based method was able to handle the nonlinear inverse problem and to provide an estimation of the uncertainty in the estimated parameters. The main research activities are listed below:

- Estimation of both dynamic parameters (i.e., saturation of gas and water; pressure) and static parameter (i.e. porosity). Here, the acoustic impedance data were used for the inversion.
- Estimation of changes in porosity, pressure, water-gas saturations using time-lapse acoustic impedance data.
- Testing of the methodology on a real field scenario. Here, we used time-lapse life of field seismic data (LoFS) from the Ekofisk field. Inverted acoustic impedance data was used as seismic attribute.
- Further extension and testing of the methodology using other seismic attributes. Here, we compared the time-strain attribute with acoustic impedance attribute. We performed the tests for both synthetic and real field data.

- Implementation of the correlation-based localization to mitigate ensemble-collapse.

3.2 Seismic History matching using the ensemble-based method

Also, in this study, we considered the Ekofisk field which is a compacting reservoir. In the case of a large field like the Ekofisk , it is always a challenge to set up and test the methodology. Thus, it required a major undertaking and a careful planning to define the scope. For instance, we needed to decide whether we should aim for a full field history matching or limit the study by using a sector model. Initially, we carried out various simple tests (with limited number of realizations) to investigate the performance and stability of our workflow. For example, we tested cases with and without localization, iterative versions of the ensemble smoother etc.

The main research activities are listed below:

- Adaption of the compaction logic to the OPM (open-source porous media) simulator. In our work, we used OPM as the simulator instead of Eclipse.
- History matching using real field production data. In this test, we updated for isotropic permeability field. We tested both distance and correlation-based localization schemes. It was observed that both localization methodologies performed well. However, the distance-based localization showed the lowest final data-misfit. Further, we tested for anisotropic 3D permeability fields.
- We did several tests on history matching using seismic data. Here, inverted acoustic impedance was considered as seismic data or attribute. Further, correlation-based localization was used. Various approaches were being investigated to integrate seismic data optimally. The tested approaches are listed below:
  - Seismic data integration coming from all the active reservoir grid blocks.
  - Using the seismic data by averaging formationwise.
  - Sparse representation of the seismic data to further reduce the data size.
  - Implementation of well-mask to extract data near the well location discarding the data away from the wells.

  The results from this work showed that the data mismatch for both production and seismic data reduced only if we considered well-mask to extract seismic data near the well locations, rather than using seismic data coming from all the reservoir gridblocks or averaging over the formations. The reasons could be many, for example, poor fit between simulated and real acoustic impedance, uncertainty in the petro-elastic model, seismic resolution, improper acoustic impedance inversion etc.

4. Conclusion(s)

We developed a method to invert for petrophysical parameters using various seismic attributes as input. The method was tested for both synthetic and real field scenarios with promising results. In another work, we extended and implemented our recently developed seismic history matching workflow (4DSHM) in a real field compacting reservoir scenario. Here different strategies of assimilating of seismic data were tested. The results for this particular study, showed that only the case with well-mask was able to reduce both production and seismic data mismatch separately. However, further investigation is required to draw a firm conclusion.

5. Future work/plans

We plan to write a journal paper on seismic history matching based on our results (depending upon the approval from ConocoPhillips).

6. Dissemination of results

Here some of the relevant articles are listed below:

- Bhakta, T., Tolstukhin, E., Pacheco, C., Luo, X., & Nævdal, G. Decoupling of changes in pressure-saturation and porosity fields from time-lapse seismic data using an ensemble based method for a compacting chalk reservoir. In SEG Technical Program Expanded Abstracts 2020 (pp. 3739-3743). Society of Exploration Geophysicists.

- Bhakta, T., Tolstukhin, E., Pacheco, C., Luo, X., & Nævdal, G. Discrimination of changes in pressure-saturation and porosity fields from time-lapse seismic data using an ensemble-based method. In Workshop on ensemble-based 4D seismic history matching. The National IOR Center of Norway. 2020-10-14 (presented online).

- Bhakta, Tuhin; Luo, Xiaodong; Lorentzen, Rolf Johan; Nævdal, Geir; Valestrand, Randi. Estimation of pressure-saturation and porosity fields from seismic acoustic impedance data using an ensemble-based method. Presentation at ConocoPhillips; 2018-08-30 NORCE

- Lorentzen, Rolf Johan; Bhakta, Tuhin; Grana, Dario; Luo, Xiaodong; Valestrand, Randi; Nævdal, Geir. History Matching of Real Production and Seismic Data in the Norne Field. Presentation at ConocoPhillips; 2018-08-30 NORCE

- Bhakta, T., Tolstukhin, E., Pacheco, C., X. Luo, and G. Nævdal. "Estimation of pressure-saturation and porosity fields from seismic acoustic impedance data using an ensemble-based method - a case study from a compacting reservoir". ECMOR XVI-16th European Conference on the Mathematics of Oil Recovery. 2018.

- Bhakta, Tuhin. "Improvement of pressure-saturation changes estimations from time-lapse PP-AVO data by using non-linear optimization method." Journal of Applied Geophysics 155 (2018): 1-12.

- Bhakta, T., X. Luo, and G. Nævdal. "Estimation of Pressure-Saturation and Porosity Fields from Seismic AVA Data Using an Ensemble Based Method." IOR 2017-19th European Symposium on Improved Oil Recovery. 2017.

- Bhakta, Tuhin, et al. "Estimation of pressure-saturation and porosity fields from seismic acoustic impedance data using an ensemble-based method." 2017 SEG International Exposition and Annual Meeting. Society of Exploration Geophysicists, 2017.

- Bhakta, Tuhin; Avseth, Per Åge; Landrø, Martin. Sensitivity analysis of effective fluid and rock bulk modulus due to changes in pore pressure, temperature and saturation. Journal of Applied Geophysics 2016; Volume 135. s. 77-89

- Bhakta, Tuhin: "Estimation of reservoir parameter changes using 4D seismic data for compacting reservoir." Presented at IOR Norway Workshop; 2016-04-25.

- Bhakta, Tuhin. "Better estimation of pressure-saturation changes from time-lapse PP-AVO data by using non-linear optimization method." 2015 SEG Annual Meeting. Society of Exploration Geophysicists, 2015.