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Updating the Simulation Model Using 4D-derived Fault Transmissibility Multipliers - An Application to the Heidrun Field

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SUMMARY

The quantification of the sealing capacity of fault rock represents one of the major challenges in the study of compartmentalized reservoirs. In particular, fault seal properties may degrade flow affecting the recovery whilst the reservoir is depleted. In order to represent the fault seal behaviour in reservoir models, well log data is tradionally employed to derive fault transmissibility multipliers. These data carry a large uncertainty and are restricted by the well data coverage. Based on this observation, this study builds on the work presented in Benguigui et al. (2008) in which statistics of the 4D seismic are used to quantify fault properties in areas with poor well data control. In this work an automatic history matching procedure is implemented which incorporates the 4D estimates. By evaluating a misfit function, fault multipliers are randomly selected according to an uncertainty window defined by the errors in the 4D prediction. It is found that including such a workflow in the Heidrun field not only reduces the mismatch between simulation and historic data but also increases the spatial correlation with the observed 4D seismic signature.

Introduction

As part of the study of compartmentalized reservoirs, the quantification of the fault sealing capacity represents a key factor to optimise the field development. Traditionally, inter-compartment communication has been linked to the understanding of the fault gouge which in turn is dominated by the rock properties. In particular, log data (e.g. Gamma Ray), is employed to populate the fault sealing properties which can then be incorporated into the simulation model by means of transmissibility multipliers (Manzocchi et al., 1999). As a consequence, previous approaches are highly restricted on available well data coverage which can introduce considerable uncertainty.

Based on this observation, this work builds on the technique proposed by Benguigui and MacBeth (2008) in which statistics of the 4D signature are used in the ETLP group to invert for the fault permeability and hence fault transmissibility multipliers. In this method, spatial coverage of the time-lapse seismic data is used as an advantage to help determine the fault property estimates. Here, the method is now employed to assess the fluid flow properties of faults separating four major compartments of the Heidrun field. In this case, a history matching workflow is also applied by considering the uncertainty associated with the 4D fault multiplier estimation.

Method

The overall spatial variability of the 4D signature represents a valuable tool to constrain reservoir flow, which for compartmentalised reservoirs is strongly dominated by the effective fault permeability. The workflow employed in this study (Figure 1) make use of the observations detailed in Benguigui and MacBeth (2008) in which the 4D signature is used to propagate fault properties (i.e. fault permeability) in areas with poor well control. Such methodology relies on the extraction of two statistical measurements defined as *4D inter-compartment difference* and *4D Spatial Variability*, both of them derived from a 4D attribute map. The approach showed that a quadratic polynomial expression can be used as the best fit function for the fault permeability. The coefficient is then calibrated in a sector with known (geologically based) fault properties. Given this approximation it is possible to calculate fault permeability for segments with poor well control.

4D derived fault permeabilities extracted from the seismic grid are re-sampled to the reservoir grid by upscaling the estimation via an arithmetic average method. Using the upscaled representation of the 4D estimation as well as the size, permeability of the juxtaposed cells and fault thickness (calculated from fault throw), the fault transmissibility multiplier is derived as described in Manzocchi et al. (1999). The new 4D fault multiplier is now applied to the grid-blocks affected by the fault; hence 4D derived fault properties are effectively introduced into the simulation model by means of these modified cells.

Considering the uncertainty of the 4D estimation, a Monte-Carlo formulation is employed in an automatic history match approach in which the fault multiplier is randomly selected between a pre-defined minimum and maximum according to a probability density function (pdf) defined by the errors in the 4D estimation. The following cost function J is used to permit the evaluation of the misfit associated with each simulated realization:

$$J = \sum_{N} \frac{\left(Q_W - Q_{W_{OBS}}\right)^2}{\sigma_Q^2} \qquad (1)$$

where Q_w and Q_{Wobs} are given by the estimated and observed values for the water rate at each producer well.

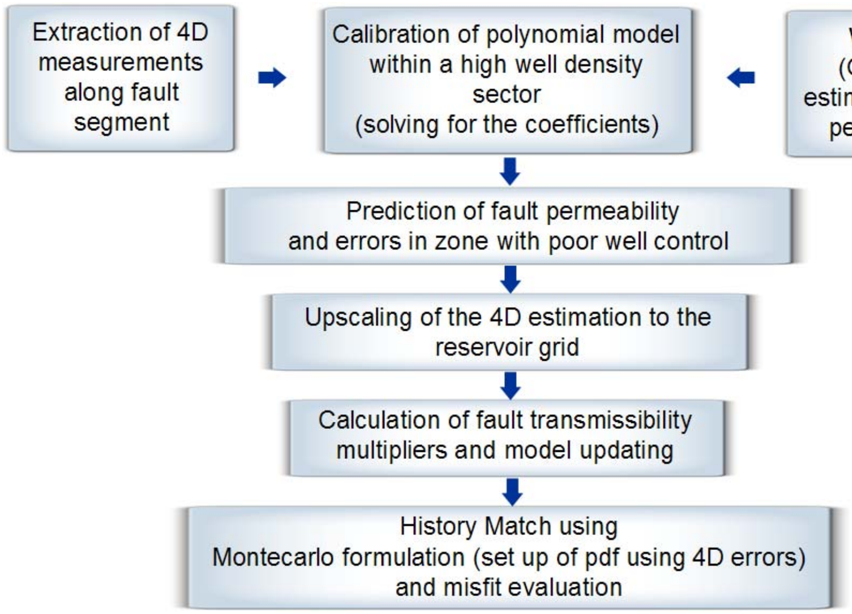

Figure 1. Workflow applied in this study.

Application to the Heidrun Field

The Heidrun field is one of the major oil accumulations in the Norwegian continental shelf, containing more than 186 M S.m^3 of oil and 41.6 G S.m^3 of gas. Production started in 1995, and included in the drainage strategy was pressure maintenance by up-flank gas and down-flank water injection together with gas cap expansion. Also, as part of the surveillance plan, several time-lapse seismic surveys have been acquired over the southern part of the field (Furre et al., 2006). The Jurassic reservoir is heavily compartmentalized by a set of extensional faults which affect the connectivity hence the drainage pattern. Although several studies have attempted to characterize the fault sealing properties affecting the flow in this field, the representation of fault properties for simulation purposes is still the subject of discussion. Here, we characterize the inter-compartment connectivity of four major segments by improving the quantification of the fault reservoir properties.

In order to evaluate the time-lapse seismic signature in the ETLP group, differences in RMS between the monitor (2001) and base line surveys (1986) are extracted from a 16 ms window centred about the top of the reservoir. 4D measurements are extracted from each pair of neighbour compartments and 4D fault permeability is calculated for three major reservoir faults through calibration of the polynomial approximation via geological fault permeability values in a well-controlled sector. Values obtained are in between 0.1 and 1 mD, yet a decrease of the signal-to-noise ratio in the 4D attribute map leads to a less robust calibration process. Nonetheless, estimated fault permeability values seem to be in agreement with magnitudes showed in Knai and Knipe (1998) where fault rock types have been observed in detailed core analysis carried out in the Heidrun field.

Comparison of the time-lapse seismic signature against the upscaled representation of the 4D fault permeability values show agreement as indicated in Figure 2. Particularly, the hardening response (given by the increase of the water saturation during injection) is affected by the fault sealing properties reducing the flow along the reservoir. As shown here, higher permeability values in the top right fault are correlated with anomalies traversing the fault plane. As a consequence, leakages in this fault, enhance water flooding leading to a quick increase of the water cut values in producer wells located in the vicinity of this fault.

Conversely low fault permeability values seem to constraint the spreading of the signature, hence showing a compartmentalizing 4D effect.

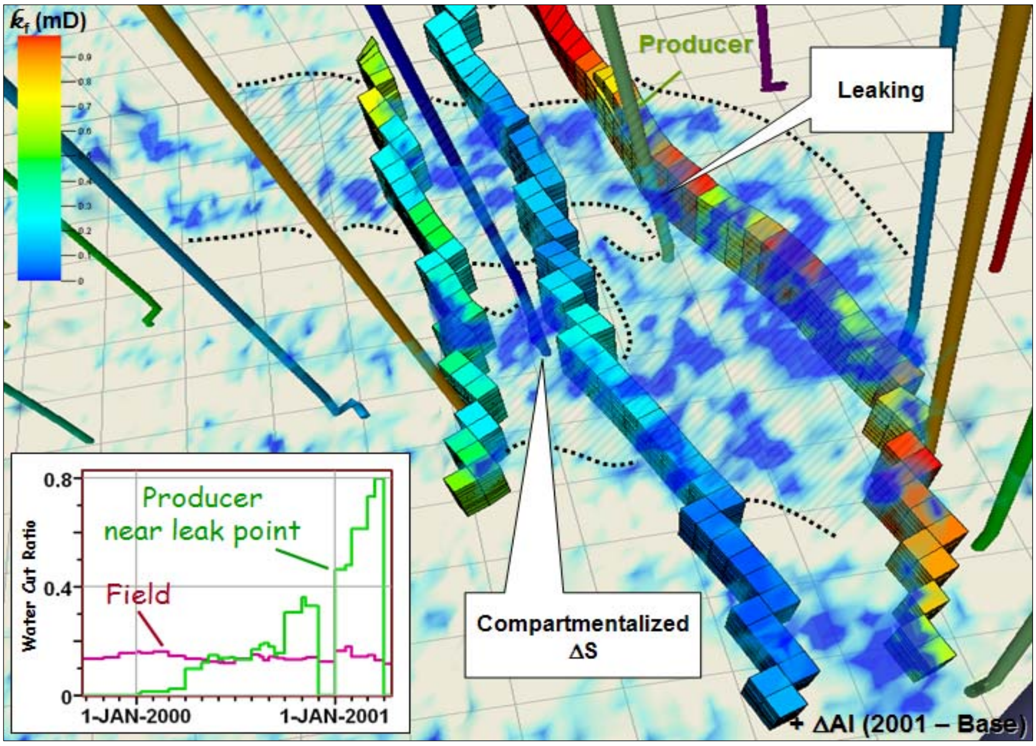

Figure 2. Comparison of the time-lapse seismic signature against the upscaled representation of the 4D derived fault permeability values.

As explained in Manzocchi et al. (1999), cell properties and the upscaled representation of the 4D derived fault permeability are used to calculate new fault multipliers, which in turn are applied to the relevant cells of the simulation model. A comparison for the simulation output (water saturation change 2001-1995) between the base case (without 4D input) and updated model (including 4D) (Figure 3) shows an enhancement of the match when the 4D fault properties are introduced into the model. Now, by considering the minimum and maximum fault permeability values given by the error quantification at each point in the fault segment, a triangular pdf is defined to automatically update the simulation model using the defined objective function to evaluate the water production history match. A Monte-Carlo approach is selected in which the fault transmissibility varies iteratively, calculating for each simulated realization the total misfit. This part of the workflow has been implemented in a sector of the field constrained by boundary conditions according to a specified Neumann flux in which discharges (Q) vary in space and time. Here, iterative changes on fault properties for the analysed faults, quickly decrease the mismatch between simulation and observation. In particular, simulated water cut for the field and individual producer wells located in the vicinity of the updated faults show a decrease in the mismatch with the historical data.

Conclusions

In a new effort to constrain reservoir flow, 4D seismic is used in the ETLP group as a tool to quantify the inter-compartment communication. Application of our methodology to the Heidrun field produces encouraging results, and suggests that 4D data can be used as a tool for deriving fault seal properties. The assessment of a geologically-consistent 4D fault transmissibility can therefore lead to improvements in fault characterization for full field flow simulation models enhancing production data matching and production forecasts.

References

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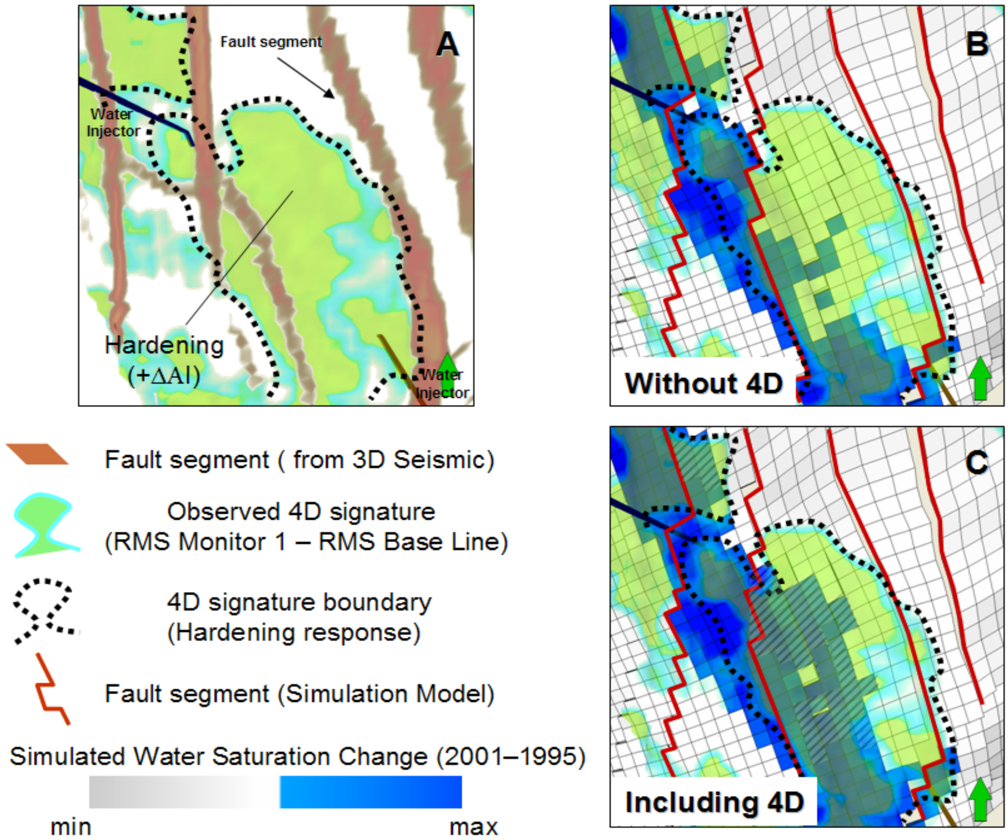

Figure 3. (A) In green colour observed 4D signature (RMS Monitor – RMS Base Line) constrained by fault segments (red). Comparison between the observed 4D signature (green) and the water saturation change (2001-1995) as derived by the simulation without (B) and including the 4D fault multipliers (C). Improvements in figure 3C (including 4D input) are highlighted with a diagonal background.