Using 4D timeshifts to estimate pressure induced processes in the overburden of the Gullfaks Field

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Introduction

The Gullfaks Field is structurally complex with sandstone reservoir units of Triassic to Middle Jurassic age. The reservoir quality is generally very good, with porosities in the range of 30-35% and permeability up to several Darcys in the most important Brent Gp. reservoir. Water injection has for several years been a key part of the strategy for optimizing hydrocarbon recovery in the main Brent reservoir. Out of zone injection has some places resulted in increased pressure in the Shetland Group in the overburden. The Shetland Group varies in thickness and comprises marl with thin layers of chalk and contain a natural open fracture system. Effects of increased pressure in the overburden are lower velocities leading to local positive time shifts up to around 5 ms observed in the 4D seismic. The high pressure in the overburden can result in potential drilling hazard and uncontrolled leakage to overburden. There are three hypotheses for the cause of the observed time shift; 1) increased matrix porosity 2) increased fracture density or 3) a combination of porosity and fracture density increase. This study aims to relate the observed 4D changes in overburden to changes in rock properties to illuminate which of these mechanisms are dominating the time shifts and to avoid drilling in potentially high-risk zones.

Methods

We used the T-matrix inclusion model (Jakobsen et al., 2003; Agersborg, 2007) for modelling effects of overpressure in the overburden. The model is designed to estimate effective elastic properties of composites made up of anisotropic ellipsoidal inclusions in an anisotropic background. The model also accounts for dual porosities, where a specified part of the total pore volume occurs as isolated inclusions. The T-matrix model was calibrated to well data where mineral composition was available. Measurements of fracture density were also used to constrain input parameters. Original fracture volume was set to 1 ‰ of total porosity. Having a calibrated model, the time shifts from porosity change and change in fracture density could be estimated separately by changing the input parameters of the model. The overburden thickness can vary, so two-way time shift is estimated per meter with the unit ms/m.

Results and discussion

Two-way time shift was estimated as a function of normalized porosity and normalized fracture density, as shown in Figure 1. The relations were approximately linear. From Figure 1, it can be seen that a relative change of 5 % in the fracture volume will have smaller effect than a relative porosity

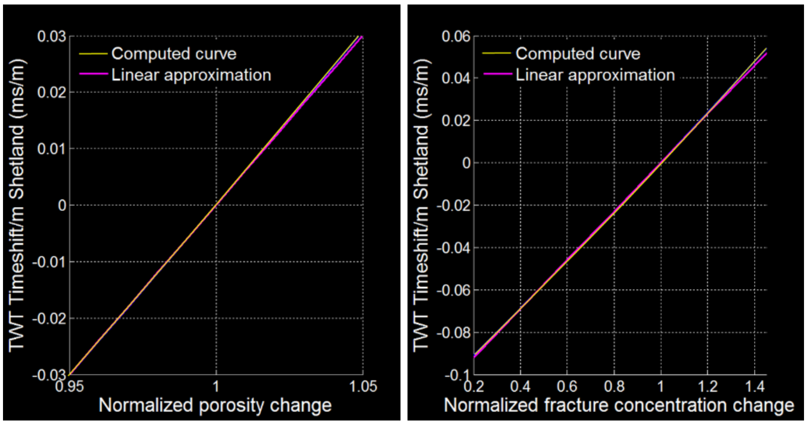

Figure 1 Estimated two way timeshift per meter formation. Left plot shows time shift as a function of normalized porosity, while timeshift in the right plot is a function of normalized fracture concentration.

increase of 5 %. Pressure effect on porosity in Shetland can be estimated by rock mechanics principles. The dynamic bulk modulus was calculated from well logs in the Shetland formation, and used to estimate the porosity sensitivity to increasing pore pressure. This implies that we assume that static and dynamic bulk modulus are the same. The approach leads to an estimated normalized porosity change of 1±0.0085 when pore pressure change is varying with ± 5 MPa which is approximately the high end of pressure variation we can expect. From this, we should expect that increased fracture density is responsible for the majority of the time-shifts. For a 100 m thick formation, the maximum modeled timeshift from porosity would then be approximately 0.5 ms. If the observed timeshift is 4 ms, the right plot can be used to quantify amount of fractures needed to explain the seismic observations. In this example a 28 % higher fracture density can explain the remaining time shift. If the rock is subjected to extensive fracturing, the background medium will no longer be a continuous phase. The rock will then consist of a gather of disconnected fragments, and the assumptions for the calibrated rock model will no longer be valid. Also the T-matrix model breaks down if the fracture density gets too high, so this can be a limitation of the approach.

Conclusions

By combining geological knowledge and rock mechanics with rock physics, we have been able to quantitatively estimate expected changes in overburden as a function of observed 4D timeshifts. This will be useful for reducing risk when drilling.

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