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INVESTIGATING THE OVERBURDEN EFFECT ON TIME-LAPSE SEISMIC BY GEOMECHANICAL MODELLING.

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Introduction

In time-lapse seismic experiments, it is important to estimate accurately the rock physics parameters at reservoir level. To solve the inverse problem (i.e., invert the rock parameters from the seismic data), additional information is needed. This extra information is obtained by solving the forward problem (e.g., using synthetic reservoir models, Angelov et al., 2004). The lack of information about time-lapse changes in the overburden due to production at reservoir level may bias the time-lapse analysis. On the other hand, information about overburden changes leads to a better quantification of the time-lapse changes in the reservoir (Hatchell et al., 2003). Stammeijer et al. (2004) analysed the time shift differences caused by compaction and by velocity changes inherent to 4D stress changes. They show that changes in the travel times can be stronger outside than inside the reservoir. Angelov et al. (2004) present a modification of Landrø's AVO approach to distinguish between pore pressure and water saturation changes in the reservoir. In our approach, we applied the AVO response from the top of the reservoir. However, we did not take into account overburden effects, which could contribute to amplitude fluctuations and travel time shifts in the seismic data. This could bias the correct quantification of the time-lapse changes in rock-physics properties. In this paper, we investigate the velocity changes in the overburden due to injection in the reservoir. We present the results of our modeling, where we used a number of synthetic geomechanical models with several hardnesses of the reservoir. By applying ray theory on our models, we compute the time shifts inferred from stress changes in the overburden that were calculated geomechanically. The magnitude of the time shift depends on the rock properties of the model (i.e., reservoir and surrounding medium), as well as on the lateral width and depth of the reservoir and geometrical parameters of the model. The intensity of depletion can also have a significant contribution to overburden transmission effects.

Modelling

- To build the geomechanical model we used the “Diana” software package. This modelling is based on Hooke's law that is a linear stress-strain relationship. The linear relationship allows us to expect the same amount of time-lapse changes due to depletion and injection in the reservoir. The model consists of two parts: 1) reservoir and 2) surrounding medium (see Fig. 1). In our modelling experiment, we assumed that the surrounding medium is homogeneous. The input parameters used in “Diana” are the geomechanical properties of the rocks (i.e., Young's modulus, Poisson's ration and density). The relationship between effective stress and elastic constants given by Wang (2002) for “North Sea” shales has been used for the derivation of the initial parameters of the surrounding medium. We used typical reservoir parameters from the “North Sea” in the synthetic reservoir model, which consists of poor consolidated sands and live oil (Mavko et al., 1998). Six models were compiled with different types of reservoirs. The reservoirs in the different models are obtained for different values of the Young modulus, while the surrounding medium is the same for all the different models. The values of the Young modulus are a function of the porosity in the reservoir. For each of the models, three different scenarios of injection in the reservoir are simulated, with pore pressure increases of 5, 15 and 25 MPa with respect to the initial effective stress of 26 MPa. The results from pore pressure injection of 25 MPa have not been analyzed.

Model	E_{sur} [GPa]	E_{res} [GPa]
Model 1	11.299	7.394
Model 2	11.299	7.059
Model 3	11.299	6.739
Model 4	11.299	6.434
Model 5	11.299	6.143
Model 6	11.299	5.864

Table 1: The six different initial models used in the modelling part with the Young modulus of the reservoir (E_{res}) and surroundingly medium (E_{sur}).

- The output of “Diana” is in the form of displacement and changes in the effective stress. To detect the velocity changes in the overburden as function of changes in the effective stress, we applied the relationship between compressional wave velocity and effective stress given by Wang (2002). The maximum displacement is on the order of 30 cm, thus the effect of displacement on the travel time attribute is not important. To validate the results of our modelling, we applied an independent calculation of displacement due to injection using the analytical solution suggested by Geertsma (1973). Both methods gave similar results, hence we could consider the effect of displacement to be insignificant for our modelling cases.

Time-shift

To monitor the changes in travel time as a result of production and overburden effects, we applied ray theory. In our investigation, we used only the zero offset for which the effect of angle inclination is not taken into account.

Results

The time shift inherent to the overburden effect is plotted in Fig. 2 and Fig. 3. Fig. 2 shows the minimum of the time shifts at the center of the top level of the reservoir, whereas in Fig. 3 the maximum time shifts at the edges of the reservoir are illustrated. The reason for the two different time shifts (i.e., minimum and maximum) is the fact that the maximum stress changes in the surrounding medium are concentrated at the boundary between the reservoir and the side-burdens (Mulders, 2003). The results are presented in Table 2.

	Δt [ms]		$\Delta t/t$ [%]	
Different models	$5[MPa]$	$15[MPa]$	$5[MPa]$	$15[MPa]$
Model 1	$0.3 \backsim 0.5$	$0.9 \backsim 1.5$	$0.02 \backsim 0.03$	$0.06 \backsim 0.1$
Model 2	$0.32 \backsim 0.54$	$1 \backsim 1.62$	$0.02 \backsim 0.03$	$0.06 \backsim 0.1$
Model 3	$0.33 \backsim 0.56$	$1 \backsim 1.68$	$0.02 \backsim 0.03$	$0.06 \backsim 0.1$
Model 4	$0.34 \backsim 0.59$	$1 \backsim 1.77$	$0.02 \backsim 0.04$	$0.07 \backsim 0.11$
Model 5	$0.34 \backsim 0.62$	$1.1 \backsim 1.85$	$0.02 \backsim 0.04$	$0.07 \backsim 0.12$
Model 6	$0.37 \backsim 0.65$	$1.1 \backsim 1.85$	$0.02 \backsim 0.04$	$0.07 \backsim 0.12$

Table 2: Time shift (Δt) and the ratio between time shift and two-way travel time (t) to the top of the reservoir ($\Delta t/t$). The pressure injection are denoted at the top of the columns.

As we see from Fig. 2, Fig. 3 and Table 2, the time shift increases with increasing injected pore pressure, as well as decreasing hardness of the reservoir, see Table 1. By increasing the injected pore pressure, sideburdens push more into the reservoir and vice versa. In addition, the stress changes will increase in the surrounding medium of the reservoir. When the reservoir is softer, it will allow sideburdens to push more into the reservoir so that the stress changes in the surrounding medium increase. Because we use the relationships suggested by Wang (2002) to transform the changes in stresses into velocity time-lapse changes, every increase of stress changes will lead to an increase in velocity changes. This trend is clearly seen in Fig. 2, Fig. 3 and Table 2. The time shifts vary from 0.3 to 2 ms, which are much smaller than the two way travel time to the top of the reservoir (i.e., less then 1%).

Conclusions

The results from our geomechanical modelling lead to the conclusion that for soft reservoirs, the time shift inherent to overburden stress changes (i.e., the maximum of 1.85 ms) could be detected in time-lapse seismic reflection data. However, this overburden induced time shift is smaller than 1% of the two-way travel time to the top of the reservoir. Hence the travel time changes inside the reservoir are bigger then the changes in the overburden, which is in disagreement with the observation of some real data examples (e.g., Hatchell et al., 2003, Stammeijer et al., 2004).

Acknowledgments

This research is supported by the Technology Foundation STW, applied science division of NWO and the technology program of the Ministry of Economic Affairs (grant DAR5763). We thank Dr. Paul Hatchell (Shell) and Dr. John Verbeek (NAM) for suggesting the investigation of overburden effect. The authors would like also to acknowledge Dr. Bogdan Orlic (TNO) for his technical and scientific support, as well as Ir. Boris Vladov Angelov (SAP) for the advices in the computational part of our research.

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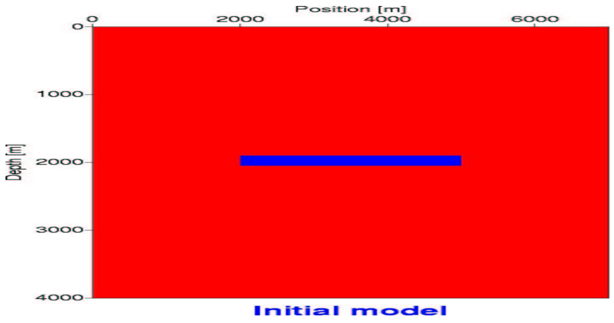

Figure 1: Initial model, i.e. reservoir (in blue) and surrounding medium.

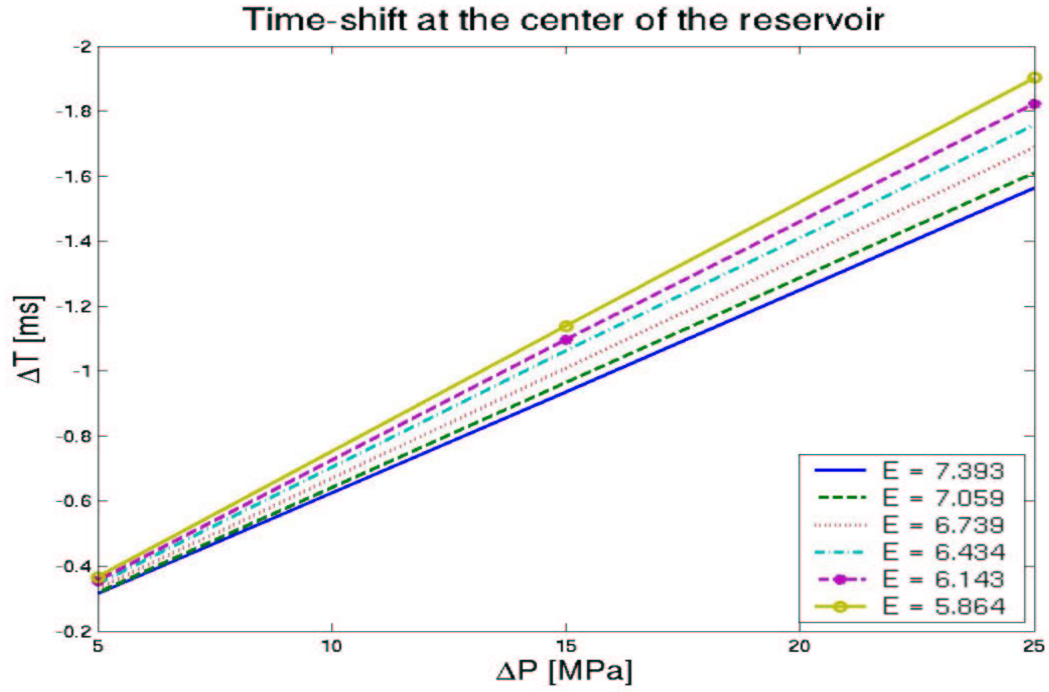

Figure 2: The minimum of the time shifts, which occures at the center of top of the reservoir, for models with a different reservoir geomechanical property (Young's modulus).

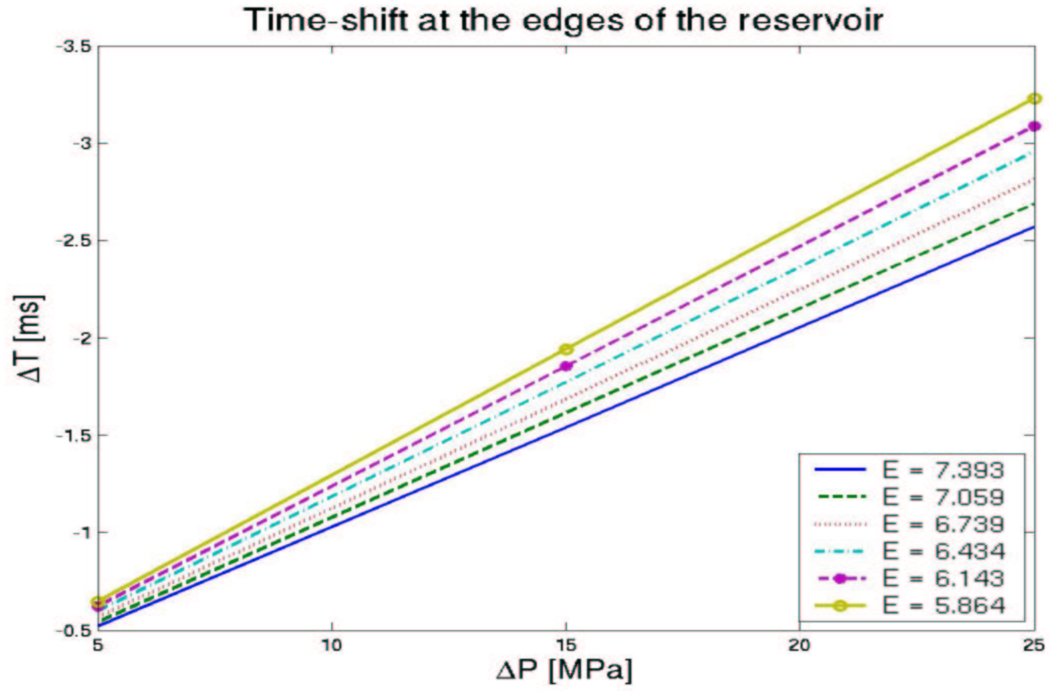

Figure 3: The maximum of the time shifts, which occures at the edges of top of the reservoir, for models with a different reservoir geomechanical property (Young's modulus).