4th International Workshop on Rock Physics 29 May - 2 June 2017, Trondheim, Norway

Stress Path Dependent Stress and Strain Sensitivity as seen by Overburden Shale

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Introduction

Stress-induced slow-down of seismic waves in the overburden constitute an important attribute for identification of depleting reservoir pockets (Kenter et al., 2004). The stress changes in the overburden causing velocities to change are controlled by the pore pressure change in the depleted areas, but also by their geometry (aspect ratio and tilt), by elastic contrast between the overburden and the reservoir, and by non-elastic behaviour and presence of fractures. In this work, results from ultrasonic laboratory measurements are combined with outcome from geomechanical modelling to assess expected *in situ* velocity changes.

Methods

Laboratory experiments have been performed with a variety of field shale cores, taken from overburden strata above different reservoirs. The samples are all well preserved, and by measuring the pore pressure response, thought to be fully saturated under stress. The cores have been loaded to their anticipated *in situ* stress and pore pressure, followed by loading and unloading along different stress paths with 5 MPa change in axial stress, including undrained constant mean stress, uniaxial stress, uniaxial strain and isostatic load cycles. An additional segment of constant net stress was also applied. Multidirectional P- and S-wave velocities at ultrasonic frequencies (0.3 – 0.5 MHz) were measured during the tests.

Results

Figure 1 shows as an example of the stress path sensitivity of the stress and strain dependences of the P-wave velocity along the symmetry axis (v_{Pz}), denoted as $S_{Pz} = \frac{\Delta v_{Pz}}{v_{Pz}\Delta\sigma_z}$ $R_{Pz} = \frac{\Delta v_{Pz}}{v_{Pz}\Delta\varepsilon_z}$. The stress path is defined as the ratio between change in stresses perpendicular and parallel to the symmetry axis, $\frac{\Delta\sigma_r}{\Delta\sigma_z}$.

This test along with tests on other shales shows that the resulting stress sensitivity is small, following close to a linear trend as a function of stress path. The R-factor exhibits much more significant stress path dependency as a result of decrease in axial strain when moving from constant mean stress (= -1/2) to isostatic (=1) stress path.

Discussion

The linearity of the stress sensitivity in Figure 1 is agrees with general observations along given stress paths besides being a result of relatively small stress cycles. Slight differences can be seen between unloading and loading behaviour (the figure shows the average), with limited effect on the displayed trends. Both undrained and drained behaviour are well described by fitting the data to a linear relationship in terms of stress and pore pressure changes (Holt et al., 2016). The stress sensitivity is small in undrained conditions, but markedly larger if drained loading is applied. *In situ* behaviour of the overburden is likely to be undrained over time periods relevant for reservoir monitoring. Theoretical models describing the observed behaviour will be discussed. Expected *in situ* stress and strain sensitivities are shown, based on generic geomechanical modelling and the given experimental results. Note that dispersion may cause different stress and stress path sensitivity at seismic frequencies.

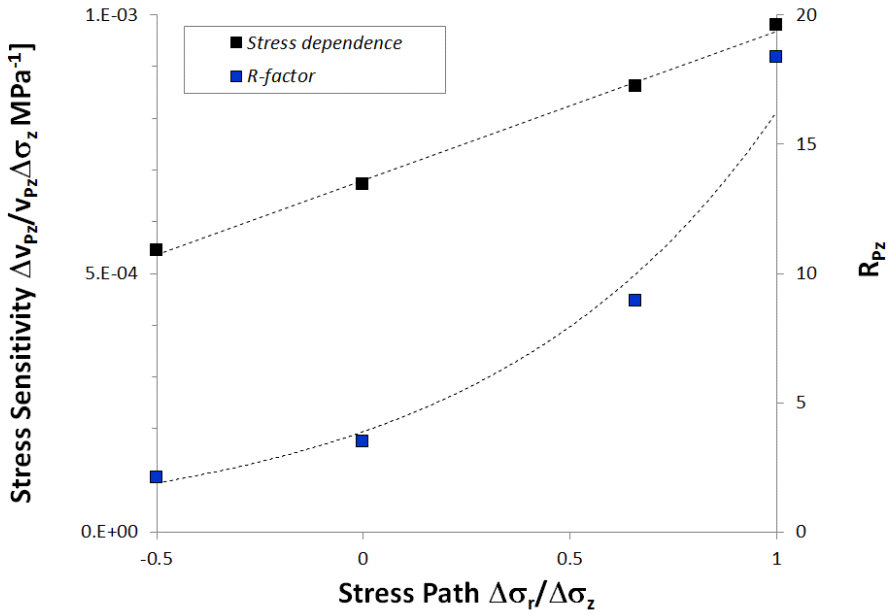

Figure 1: Stress and strain sensitivity of ultrasonic P-wave velocity ⊥ bedding in a soft field shale core with 24 % porosity and 76 % clay content plotted against stress path for a set of undrained load-unload cycles. Trendlines are shown as guides to the eye.

Conclusions

Undrained stress dependence in high porosity and high clay content shales is small, but still sufficient to be observed in time-lapse seismic because of the large volumes of rock affected by stress changes during reservoir depletion. The strain dependence (*R*-factor) appears to be a first order probe of *in situ* stress path, if evaluated locally rather than as an average over the full overburden.

Acknowledgements

This work is financed by the The Research Council of Norway and participating companies in the JIP "Shale Rock Physics" at SINTEF Petroleum Research: BP. DONG Energy, Engie, Maersk and Total.

References

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