A-23 USE OF PP AND PS TIME-LAPSE STACKS FOR FLUID-PRESSURE DISCRIMINATION

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Abstract

A complementary method to achieve quantitative information about reservoir property changes during production is to measure shift in two-way traveltime within a given reservoir section. A practical example of how this method can be used to give additional information about pressure and saturation changes in reservoir segment, is given in Landrø, 2001, Landrø, 2002 and Landrø et al., 2003.
In this paper we investigate how combined use of time-lapse PP and PS seismic data can be processed and analyzed for the discrimination between pressure and saturation changes. To compute the PP and PS reflection coefficients we use an approach developed by Ursin and Stovas (2002). To use amplitudes from the seismic stack sections, we sum the PP and PS reflection coefficients within the opening angle, which is estimated from the maximum offset on the PP and PS gathers. The difference in seismic amplitudes between the unknown and initial fluid-pressure conditions is used to predict the change in both water saturation and effective pressure. The uncertainties in saturation and pressure are expressed by the uncertainties in PP and PS stack amplitudes. This approach is applied on the synthetic data set from the Gullfaks Field.

Method

The paper focus on how to combine time-lapse PP and PS stacks for optimal discrimination between pressure and saturation effects. We use the Gassmann (1951) model to describe fluid saturation changes and the Hertz-Mindlin (Mindlin, 1949) model to describe pore pressure changes. The validity of both these models may be discussed. However, we hope that the models are sufficiently correct to be used for our purpose: to study how various seismic parameters can be optimised with respect to robust estimation of pressure and saturation changes. A similar approach was used for anisotropic reservoir rocks in Stovas and Landro (2002a). The reliability of discrimination between pressure and saturation was investigated in Stovas and Landro (2002b).

Discrimination between water saturation and pressure from PP and PS stacks

The normalized stacked reflection coefficients can be obtained from equations for reflection coefficients by integration over the maximum opening angle span. Weak-contrast reflection coefficients are used in the sensitivity analysis, while exact reflection coefficients are used for the saturation-pressure discrimination.

From Stovas and Landro (2002b) we have

$$\begin{pmatrix} \Delta R_{PP}^{\Sigma} \\ \Delta R_{PS}^{\Sigma} \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \begin{pmatrix} \Delta S \\ \Delta P/P_0 \end{pmatrix}, \qquad (1)$$

where the changes in the normalized stacked reflection coefficients are the result of small changes in saturation ΔS and pressure ΔP. This transformation matrix $\mathbf{B}_{\Sigma} = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} = \mathbf{B}_{\Sigma}(S,P)$ represents the linear operator, which maps the input vector of the change in saturation and pressure into the output vector of the change in PP and PS seismic amplitudes.

Reliability of fluid-pressure discrimination

The reliability of discrimination between water saturation and pressure changes depends among the other factors on the angle α between isolines $\Delta R_{PP}^{\Sigma} = C_1$ and $\Delta R_{PS}^{\Sigma} = C_2$ (see Figure 1), where C_1 and C_2 are given constants. From equation (1) we can define

$$\tan\alpha = \frac{b_{11}b_{22} - b_{12}b_{21}}{b_{11}b_{21} + b_{12}b_{22}} = \frac{\det \mathbf{B}_{\Sigma}}{b_{11}b_{21} + b_{12}b_{22}} \qquad (2)$$

The uncertainties in fluid saturation and pressure changes can be expressed from uncertainties in PP and PS stack amplitudes

$$\delta S = \frac{1}{\det \mathbf{B}_{\Sigma}}\left(b_{22}\delta R_{PP}^{\Sigma} - b_{12}\delta R_{PS}^{\Sigma}\right) \qquad (3)$$

$$\frac{\delta P}{P_0} = \frac{1}{\det \mathbf{B}_{\Sigma}}\left(-b_{21}\delta R_{PP}^{\Sigma} + b_{11}\delta R_{PS}^{\Sigma}\right) \qquad (4)$$

In Figure 1 we show how the uncertainties in PP and PS stack amplitudes relate to the uncertainties in fluid saturation and pressure. In addition to this, we have systematic uncertainties related to rock physic parameters, saturation-pressure models etc.

Synthetic application

To test this approach on synthetic data three models (Model I, II and III) related to the Gullfaks Field were chosen (Arntsen, 2002). Model I has a known initial condition, while Model II and Model III have unknown fluid-pressure conditions which have to be predicted. For all three models the synthetic PP and PS seismic data were simulated and processed. There are 8 types of reservoir rock (Brent Formation) overlayed by shale (Shetland Formation). Reservoir rocks are named SM1, SM2,…, SM8. First we compute PP and PS stacked reflection coefficients and subtract the corresponding values for initial fluid-pressure conditions. These differences $\Delta R_{PP(PS)}^{\Sigma}(S,P)$ are composed into reflection pattern.

The reflection patterns are computed versus water saturation and effective pressure for all interfaces (pattern for Shetland and SM1 is plotted in contour lines in Figure 2). The thick lines are related to zero values of ΔR_{PP}^{Σ} and ΔR_{PS}^{Σ} or Model I.

The difference plots are given in Figure 3 and 4 for PP and PS sections. Note that the difference in PS sections for Models III and I is much more pronounced compared to the difference in PS sections for Models II and I. We use seismic amplitudes from the top reservoir only, because the deeper part of the section is shifted differently for each model. To make the stacked reflection coefficients and amplitudes on seismic sections consistent, we calibrate reflection coefficients for initial saturation-pressure condition and amplitudes from seismic sections for Model I. To compute the difference sections we subtract seismic section for Model II (and Model III). Seismic amplitudes along the top reservoir are picked up from difference sections, and corresponding contour lines are constructed for the interface between shale and each reservoir rock. The crossing between contours ΔR_{PP}^{Σ} and ΔR_{PS}^{Σ} gives the values for water saturation and effective pressure. The results of prediction for reservoir rock SM1 are given in Figure 5. One can see that the Model II and Model III are very good separated both in saturation and pressure. The position of data for Model II gives an explanation why the difference PS section for Model II and Model I is very weak. For all types of reservoir rock there is a very small change in PS contour lines between these two models. The reflection patterns provide us with interpretation of how saturation and pressure changes affect on the seismic amplitudes on PP and PS sections.

Conclusions

A method for fluid-pressure discrimination from PP and PS stacks is developed.

The fluid dependence is based on the Gassmann model, and pressure dependence is based on the Hertz-Mindlin model calibrated to Gullfaks data. The method is applied on a synthetic data set from Gullfaks model which mimics three time-lapse situations. The results of water saturation and pressure prediction are very close to the modelled data. The analysis of weighting factors for uncertainties in water saturation and pressure shows that for all reservoir rocks representing Gullfaks field the relative uncertainties in saturation are bigger than uncertainties in pressure.

Acknowledgements

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References

Arntsen, B., 2002, Finite-difference synthetic data of a model Gullfaks, Statoil Technical Report, N.

Gassmann, F., 1951, Elastic waves through a packing of spheres, Geophysics, **16**, 673-685.

Landrø, M., 2001, Discrimination between pressure and fluid saturation changes from time-lapse seismic data, Geophysics, **66**, 836-844.

Landrø, M., 2002, Uncertainties in quantitative time-lapse seismic analysis, Geophys. Prosp. **50**, 527-538.

Landrø, M., Veire, H.H., Duffaut, K., and Najjar, N., 2003, Discrimination between pressure and fluid saturation changes from marine multicomponent time-lapse seismic data: Paper accepted for publication in Geophysics.

Stovas, A.M. and Landrø, M., 2002a, Fluid-pressure discrimination in anisotropic reservoir rocks – a sensitivity study, paper submitted to Geophysics.

Stovas, A.M. and Landrø, M., 2002b, Optimal use of PP and PS time-lapse stacks for fluid-pressure discrimination, paper submitted to Geophysical Prospecting.

Ursin, B. and Stovas, A.M. 2002, Reflection and transmission responses of a layered isotropic visco-elastic medium, *Geophysics*, **67**, 307-323.

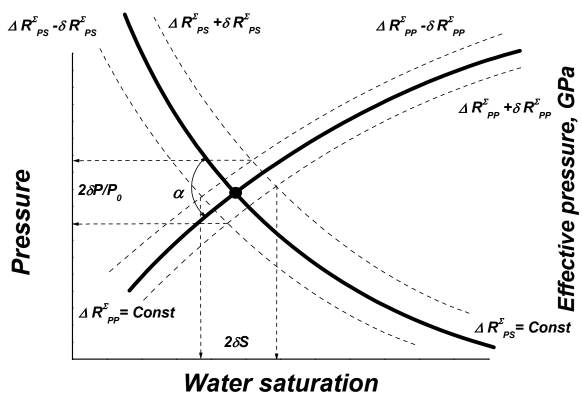


Figure 1. Saturation-pressure discrimination and uncertainties.

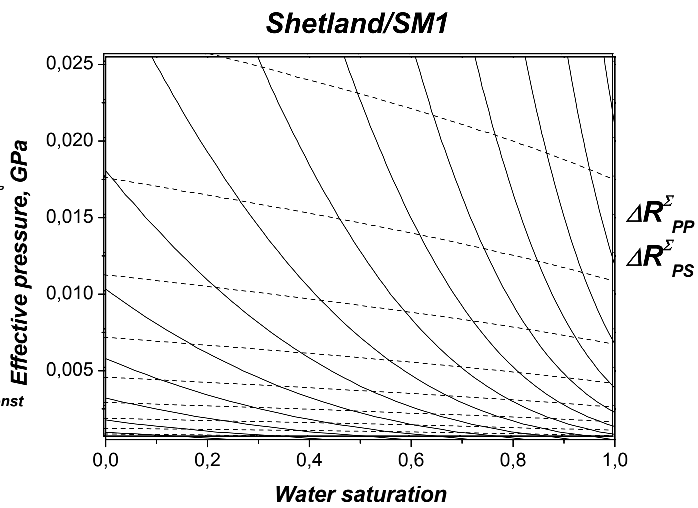
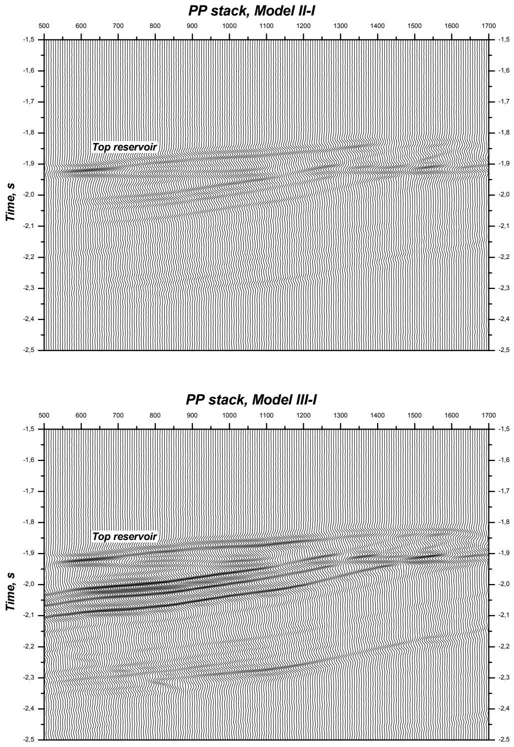


Figure 2. Reflection pattern for PP and PS stacked reflection coefficients.



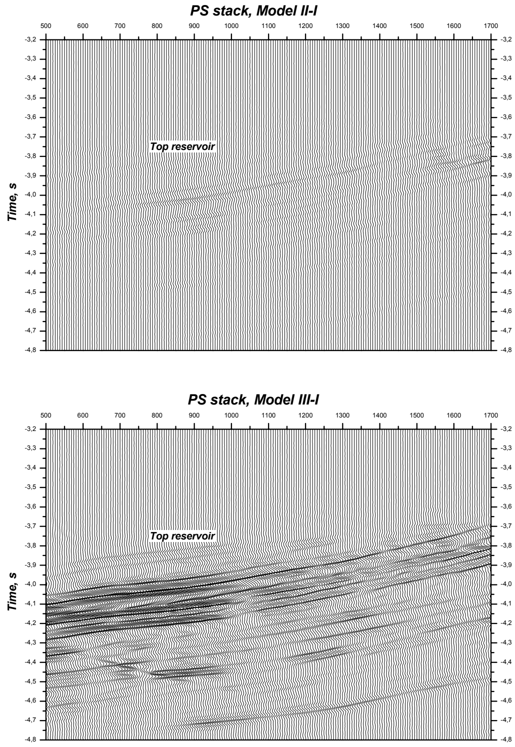


Figure 3. Difference plot for PP stacks from models II and I (to the top) and models III and I (to the bottom).

Figure 4. Difference plot for PS stacks from models II and I (to the top) and models III and I (to the bottom).

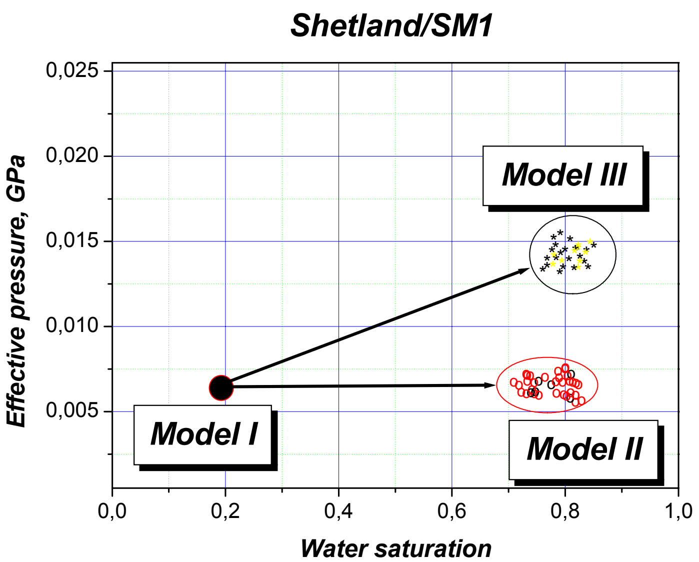


Figure 5. Prediction of water saturation and pressure changes for reservoir rock SM1.