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Rapid 4D Inversion Using A Production Facies Approach

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Summary

A P-P 4D inversion study was carried out for an oilsands project in NE Alberta using facies-based inversion, with the associated benefit of not requiring low-frequency background models. This can provide improved imaging of properties within a reasonable timeframe. The input parameters to the study include rock physics modelling of possible time-lapse production scenarios in which pore pressure, saturation and temperature vary. Notably, we did not find that the Vp/Vs ratio should increase under any of the production scenarios modelled, and data from the inversion was largely in agreement. This contrasts with several published accounts of inversion results in oilsands, and highlights the need for additional study of low frequency temperature variations in heavy oil.

Workflow

Inversion of seismic data is a valuable process to quantify the reservoir changes in the subsurface, where multiple processes are often ongoing. Simultaneous prestack inversion has been the traditional method of choice, but more recently facies-based inversion approaches have been proposed to remedy some of the former's weaknesses and to provide additional constraints where applicable (Kemper and Gunning, 2014, Gunning and Sams, 2018). The advantages of a facies approach include a reduced reliance on low-frequency model building, an improved match between inverted elastic properties and subsurface rock physics, and improved noise-handling capability.

We can approach the 4D facies inversion problem as a full inversion of baseline and monitor properties (Waters et. al., 2016). However, we can also re-arrange the problem to invert the difference between the monitor and the baseline instead, after proper registration has been achieved. This can minimize the number of facies involved while leveraging the advantages of a facies-based inversion in a single step, creating a workflow that is both rapid and effective for production geophysicists. We refer to the facies required in this workflow are 'production facies', representing the elastic changes that the reservoir has experienced between the time of the baseline and the monitor. Production facies can be parameterized by known rock physics models, and there can be some experimentation in the inversion with different subsurface processes.

Oilsands projects routinely collect 4D seismic for thermal projects to assist operations for both Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS). These are natural candidates for a production facies inversion approach, where timely results are important to influence completion decisions. In addition, there is some uncertainty in the rock physics of thermal processes (Ciz and Shapiro, 2007, Makarynska et. al., 2010, Gray et. al., 2016, Gallop and Larson, 2016) and so experimentation with rock physics parameterized facies models is desirable.

We have applied the production facies approach to P-P 4D seismic data collected over a SAGD project in NE Alberta. The workflow consists of 1) identifying sets of possible subsurface reservoir scenarios, which define production facies, 2) calculating the elastic properties associated with each scenario, 3) conditioning monitor and baseline seismic data for time-lapse inversion, 4) performing several seismic inversions with some or all of the production facies, and 5) evaluating inversion metrics and the spatial distribution of facies to arrive at a most likely scenario.

Time-lapse log suites are rarely available, and so we calculate elastic log changes based on rock physics modelling of possible cases. Figure 1 shows an example of several such scenarios that were examined using a delineation well as a baseline for the modelling (logs in black). Modelling was carried out using fluid properties from the FLAG equations (2014), and the dispersive heavy oil moduli were calculated at 50Hz. Changes due to the effective stress of the rock framework were also accounted for in the elastic models. The left hand track shows the modelled temperature for all cases, followed by the pore pressure track. The middle tracks show both the production facies and fluid saturations for a synthetic steam chamber with an isolated reservoir compartment above. The right hand tracks show the insitu logs in black along with modelled time-lapse elastic logs. The dark blue and light blue logs model the presence of a small amount of gas below the steam chamber as well as exsolved gas in the isolated reservoir compartment, the latter at two different pore pressures. The pink logs model no gas below the steam chamber as well as sufficient pore pressure to keep gas from exsolving in the isolated zone above the steam chamber. We see that the acoustic impedance decreases by varying amounts in all scenarios. More surprisingly, in light of the findings of Zhang and Larson (2016), we see that the Vp/Vs ratio decreases as well in all cases, although to a greater extent when gas is present. It is possible that the decrease Vp/Vs ratio for the heated oil scenario (no gas) is caused by inaccuracy in the dispersive fluid calculation or the fluid substitution method itself, and further study is needed; however, we found the seismic inversion generally associated a decrease in Vp/Vs ratio with heated oil as well.

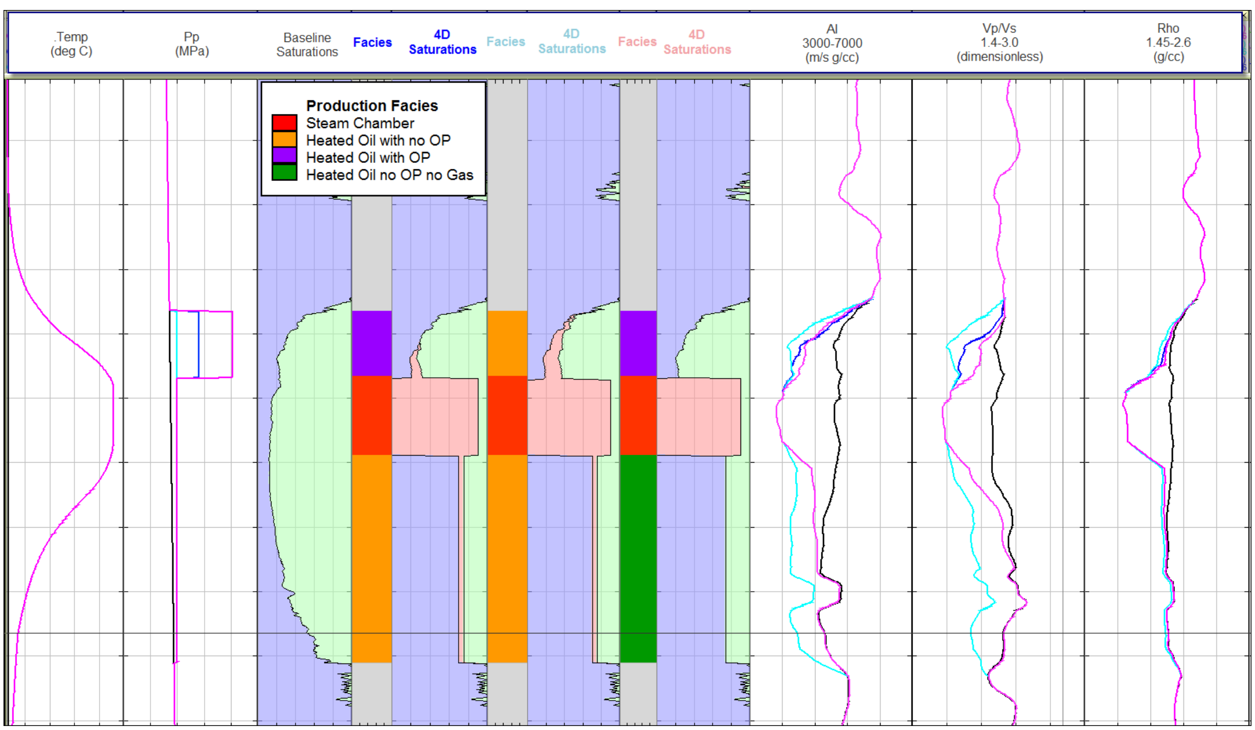

Figure 1: Colour coded reservoir scenarios including (from left) temperature, pore pressure, production facies and saturations, and the corresponding modelled elastic properties at right. Data are from an oilsands well, with black curves being the insitu (pre-production) properties.

Conclusions

We have described a workflow for 4D inversion of baseline-monitor differences using a production facies approach, the results of which will be presented. This workflow leverages the constraints of a facies-based approach, which are not possible with a standard prestack simultaneous inversion. We have used rock physics modelling as the basis for the elastic properties associated with each facies. In the area studied, the modelling did not predict an increase in Vp/Vs ratio with any of the scenarios studied, after accounting for fluid pressure, temperature and dispersion effects, as well as the response of the rock framework to stress. More study is likely needed on the low frequency behaviour of heavy oils to be able to effectively parameterize rock physics models, which in turn can be used for imaging of 4D effects.

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References

Ciz, R. and Shapiro, S.A., 2007, Generalized Gassmann equations for porous media saturated with a solid material. Geophysics, **72,** no.6, A75-A79.

FLAG Fluid Calculator: 2014 University of Houston and Colorado School of Mines Fluids / DHI consortium.

Gallop, J. and Larson, G., 2016, Linking PP and PS time-strain observations to near borehole anomalies using a linear thermo-poroelastic model, SEG, Expanded Abstracts.

Gray, F.D., Wagner, K.A., and Naidu, D.J., 2016, 3C-4D locates mobile bitumen in oil sands, CSEG, Geoconvention Abstracts.

Gunning, J., and Sams, M.S., 2018, Joint facies and rock properties Bayesian amplitude-versus-offset inversion using Markov random fields, Geophysical Prospecting, **66**, 904-919.

Kemper, M. and Gunning, J., 2014, Joint impedance and facies inversion – seismic inversion redefined. First Break, **32**, 89-95.

Makarynska, D., Gurevich, B., Behura, J. and Batzle, M., 2010, Fluid substitution with viscoelastic fluids. Geophysics, **75**, no. 2, E115-E122.

Waters, K., D., Somoza, A.V., Byerly, G. and Rose, P., 2016, Detecting production effects and by-passed pay from 3D seismic data using a facies based Bayesian seismic inversion, EAGE Expanded Abstracts.

Zhang, J. and Larson, G., 2016, Monitoring steam chamber movement using time-lapse PP-PS joint inversion, SEG, Expanded Abstracts.