Time lapse data driven low frequency model update

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Summary

In this paper a method is described to update the low frequencies of the elastic parameters coming from pre-stack time lapse inversion in a data driven manner. In the process no assumptions are made regarding the nature of the reservoir changes. Also no assumptions are made regarding the relationships between elastic parameters or reservoir parameters. The method described here can be seen as a 4D extension to a 3D updating method described by Mesdag et.al. 2010. In this way independent measures are obtained of time lapse absolute P-Impedance and time lapse absolute Vp/Vs (or $\lambda\rho$ and $\mu\rho$). These can then be compared with propagation parameters derived from 4D time shifts or velocities.

Introduction

In heavy oil Steam Assisted Gravity Drainage (SAGD) the steam chambers can vary in size up to 40-50 meters in thickness. Time lapse seismic is often used to quantify production parameters such as temperature and pressure or steam chamber development. The wavelet extracted from conventional seismic data imaging such shallow reservoirs is typically a short period one with a dominant wavelength around 30 m (20 ms). It is clear that the conventional seismic signal will only contain part of the information necessary to characterize the reservoir. Much of the information for full bandwidth inversion will have to come from the time lapse low frequency response of the subsurface, i.e. the low frequency difference in the elastic parameter models between monitor and base. Rock physics models (RPM) can be used to update the low frequency model at well control. Production data will provide the information we need to update the petrophysical well curves to the time of the monitor survey and the RPM allows us to convert this to the elastic parameters. Away from wells the seismic data may be the only hard data available.

The Method

There are several steps to this workflow. First the data need to be prepared for time lapse inversion. This means that the differences between the base and the monitor surveys need to be minimized outside the reservoir zone. For most inversions this preparation includes the alignment of the monitor data to the base data and removal of any mis-alignment between the offset or angle stacks.

The next step is a first pass time lapse inversion. First pass is meant here in the sense that there will initially be no attempt to update the low frequencies in the time lapse sense. This first pass inversion does include well tying, wavelet estimation, 3D low frequency model building, and two inversions.

The two inversions described here are the inversion of the base survey and the inversion of the difference between the base and the monitor surveys.

There are other workflows known to the industry, such as a separate inversion of the base and the monitor survey or simultaneous inversion of the base and monitor. These are not discussed here.

The result of the first pass inversion is a band limited time lapse P-Impedance and a band limited time lapse Vp/Vs, which are used to pick the tops and the bases of the steam chambers. This process is straight-forward, as you only need to interpret where there is a clear time lapse response on the P-Impedance or on the Vp/Vs. If there is little or no time lapse signal, the low frequency also does not need updating in the time lapse sense. In many cases the interpretation can be done by automatic picking, though for the weaker and ambiguous time lapse signal, interpretive knowledge and understanding of the response is essential.

After picking the tops and bases of the steam chambers the contrasts in P-Impedance and Vp/Vs are extracted over the interpreted horizons. Assuming a linear trend in the time lapse low

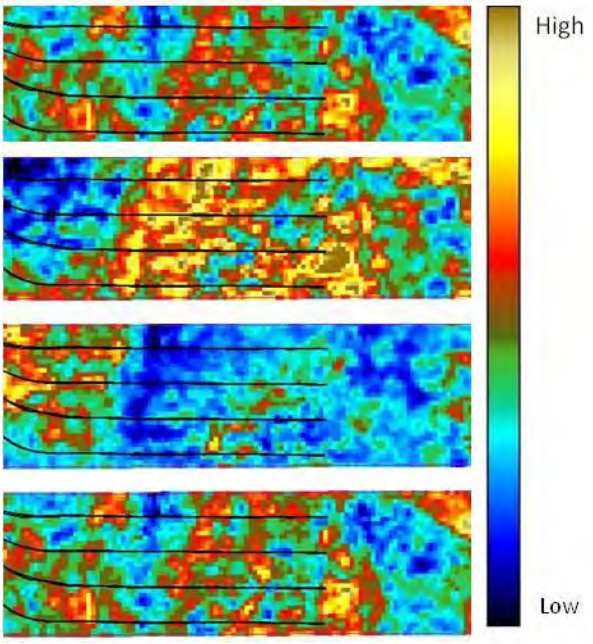

Figure 1: Top: RMS seismic amplitude extracted from base line seismic survey.
Second: RMS seismic amplitude extracted from monitor seismic survey
Third: correction factor calculated from base and monitor RMS extractions.
Bottom: RMS extraction from monitor after correction

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frequencies, the contrast information can be inserted into a time lapse low frequency model. The low frequency model is zero everywhere, except in the steam chambers.

Data preparation

When preparing seismic data for any time lapse inversion there are two steps that always need to be considered: data equalization and time alignement.

- Data equalization

  For data equalization an area above the reservoir section should be chosen, where no time lapse changes should be expected. From this area measures of equality between base and monitor can be extracted, like the RMS amplitude of the seismic data (Figure 1). If any changes are observed, this is probably due to differences in acquisition between base and monitor. These differences are likely to be pervasive throughout the seismic trace and will cause false time lapse effects.

- Time alignment

  Most inversion techniques do not account for mis-alignment of the seismic reflectivity in the inversion process. Therefore, any mis-alignment needs to be removed prior to seismic inversion.

  In the case of pre-stack inversion the correction of the mis-alignment needs to be applied both in the offset or angle direction and in the time lapse direction.

Time alignment from monitor to base

In SAGD the time shifts between base and monitor surveys can be up to several milliseconds. Time shifts can be calculated in many ways, but for relatively small time shifts, cross correlation between the two surveys usually gives satisfactory results. Time shifts with low cross correlation values need to be avoided. A method to achieve this is depicted in Figure 2d. Here a polygon on a cross-plot of the cross-correlation and time shift values is used as a mask to blank out any dubious time shifts. Prior to applying the time shifts, the undefined values are interpolated in a 3D sense.

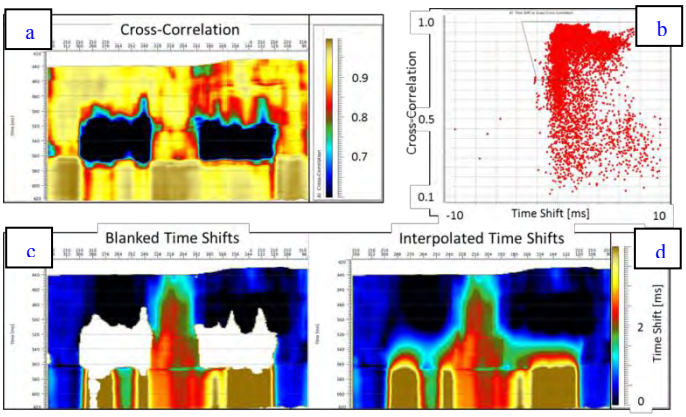

Figure 2: a) Section through a volume of cross-correlation between the base and monitor surveys b) cross-plot with the "masking" polygon, c) blanked time shifts and d) interpolated time shifts

First pass inversion

In a first pass inversion the baseline survey is inverted. Here a simultaneous inversion of partial angle stacks is performed to build a 3D full bandwidth model of both P-Impedance and Vp/Vs.

A second inversion is performed on the difference seismic data (Monitor minus Base). This is not a real physical experiment and is only valid when the time lapse signal reflection coefficients are smaller than those from the base and linearity of reflections with respect to elastic parameter contrasts may be assumed. During the inversion of the difference between the base and the monitor surveys the 3D model from the inversion of the base survey is used as the background trend. The result of the inversion of the difference between the base and the monitor surveys is low-cut filtered to remove the 3D trend. This reveals the band limited time lapse P-Impedance and the band limited time lapse Vp/Vs. An example is shown in Figure 3.

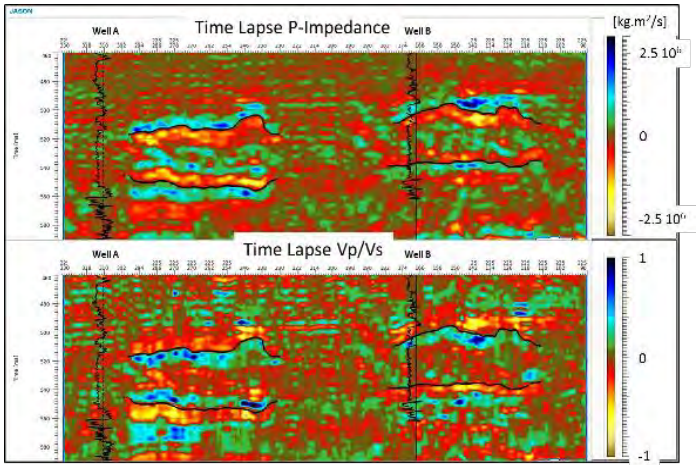

Figure 3: Band limited time lapse P-Impedance and Vp/Vs, with the interpreted tops and bases of the steam chambers

Picking the steam chamber

Based on the results of the first pass inversion the steam chambers can be interpreted. The interpretation should be placed at the zero crossing between a maximum and

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a minimum of either or both of the elastic parameters. If neither the time lapse P-Impedance or the time lapse Vp/Vs give a clear response, the interpretation cannot be performed.

Note that, depending on what phase of the production cycle the steam chamber is in, the time lapse P-Impedance response and the time lapse Vp/Vs response may be different. In some areas one may not see a P-Impedance response, while in other areas the Vp/Vs changes may be small.

Updating the time lapse low frequencies

Once the top and base of the steam chambers have been interpreted, the contrast of the elastic parameters needs to be extracted from the band limited time lapse P-Impedance and Vp/Vs. The extreme values directly above and below the interpreted time horizons are extracted and subtracted to form the contrasts. Now we have an extracted contrast for both P-Impedance and Vp/Vs around the time interpretation of the top and the base of the steam chambers.

Next the time lapse low frequency models are constructed for P-Impedance and Vp/Vs (Figure 4).

In areas where there is no production, outside the steam chambers, there is no change in the elastic properties, so the time lapse models contain zeros. Within the steam chambers the interpreted contrasts are linearly interpolated between the top and the base time interpretation. A linear interpolation is not a bad approximation, as these models will only be used to fill in the missing time lapse low frequencies, i.e. below 10-15 Hz. Finally the band limited time lapse models are merged with their respective low frequency models. A typical result is shown in Figure 5, where the models of figures 3 and 4 are merged.

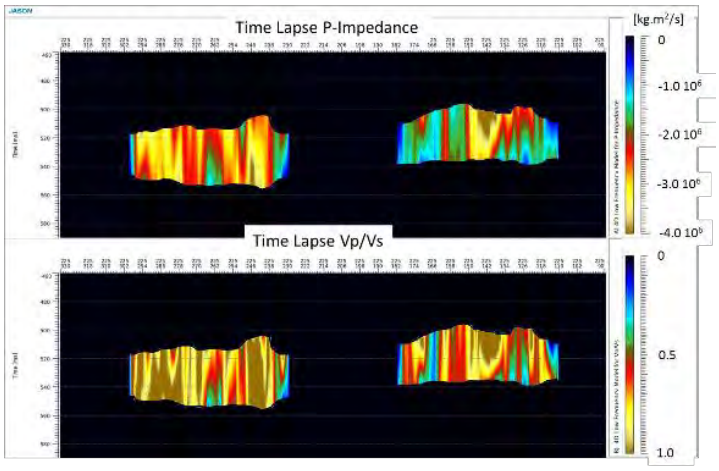

Figure 4: Low frequency models for P-Impedance and Vp/Vs.

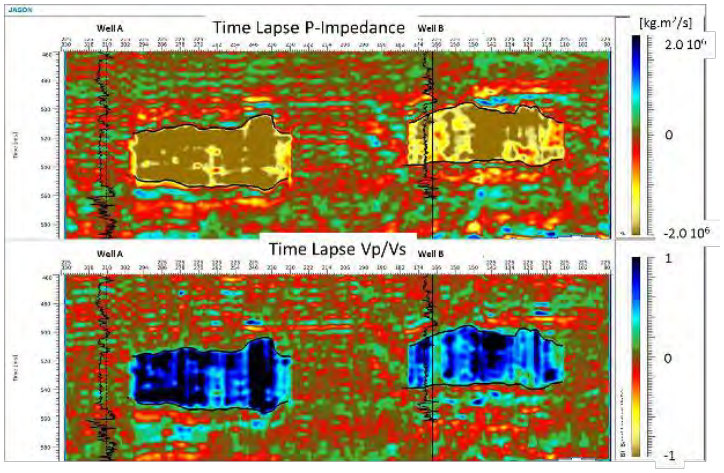

Figure 5: Full bandwidth P-Impedance and Vp/Vs after merging with the constructed low frequency models

Comparison with other data

The inversion results produced with this method can be compared with the time shift measurements obtained in the alignment process of the monitors. Time shift maps of a horizon directly below the reservoir can be compared with average time lapse P-Impedance over the reservoir (Figure 6). The time shift maps are indicative of velocity changes in the reservoir, while the P-Impedance incorporates both velocity and density changes. Comparison of the two maps indicates areas with high correlation, where the reservoir changes are dominated by velocity effects (Pad 2), but also areas with little correlation, where density and velocity changes seem to cancel out (Pad 1).

Another comparison can be made with temperature measurements in control wells close to the steam chambers. As the elastic parameter changes in the reservoir are dominated by temperature effects, there

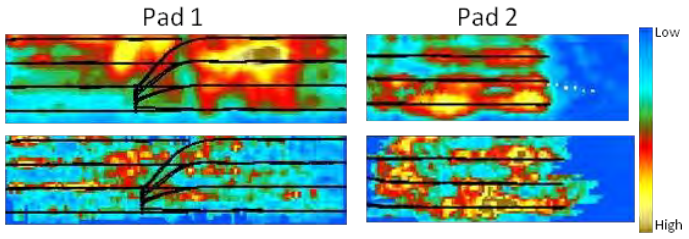

Figure 6: Top: Time shift map from horizon below the reservoir. Bottom: Mean time lapse P-Impedance within the reservoir

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should be a good correlation between the inversion results and the temperature measurements as illustrated in Figure 7.

Conclusions

A novel method to construct low frequency trend models for time lapse seismic inversion is presented. Our method to update time lapse low frequency models is based on a first pass inversion and makes no assumptions about the reservoir conditions. Nor does the method need to make any assumptions regarding relationships between elastic parameters. The method allows for quantitative reservoir characterization and direct comparison with independent time lapse measurements of the reservoir conditions.

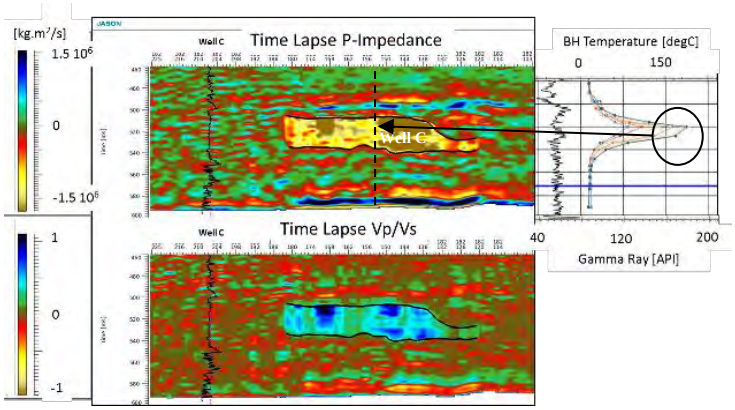

Figure 7: Temperature profile compared with inversion

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EDITED REFERENCES

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