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Interpretation of a multicomponent walkaway vertical seismic profile experiment

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Summary

A multicomponent walkaway VSP data was processed to study the rock properties of the target reservoir. Inversion and AVO attributes analysis showed no obvious gas effects in the studied interval. The observations were validated by production data. Post-stack PP-PS joint inversion was completed and compared to only P-wave inversion. Overall, they showed good consistency and the joint inversion added value to lithology prediction and fluid identification. This case study demonstrated that multicomponent VSP is an effective tool to predict rock properties, characterize the reservoir and monitor production.

Introduction

Due to its geometry, a VSP survey usually yields better resolution and a higher signal-to-noise ratio than surface seismic data. In addition, walkaway VSP geometry is suitable for AVO analysis. In this work, different rock properties were inverted from the VSP PP and PS image and prestack gathers. Interpretation of inversion and AVO attributes enabled us to better characterize the target reservoir and gave promise about how to integrate multicomponent VSP data into reservoir predicting and production monitoring.

The formation studied is a heavy oil reservoir in Canada. It was deposited as prograding tide-dominated deltas and composed of three stacked incised valleys. These incised valleys lie encased within regional deltaic, shoreface sands and marine muds. The depth of reservoir is about 500 m and it is made up of relatively unconsolidated shale-sand sequences, where fluid compressibility can have significant effect on the whole rock compressibility, which is then reflected on seismic data. Total thickness of the formation is approximately 50-75 meters (Hein et al., 2007) and it is an important resource of 9-10 API bitumen. The field is actively produced by steam assistant gravity drainage (SAGD).

The typical well logs in this area and from a neraby well are shown in Figure 1. In the reservoir zone, the gamma ray values are low which indicates clean sand deposits. High resistivity and porosity in these zones also indicate a good hydrocarbon reservoir. At the base of sand-filled valley, the resistivity becomes lower, which indicates bottom water. Above the bottom water zone is the transition zone.

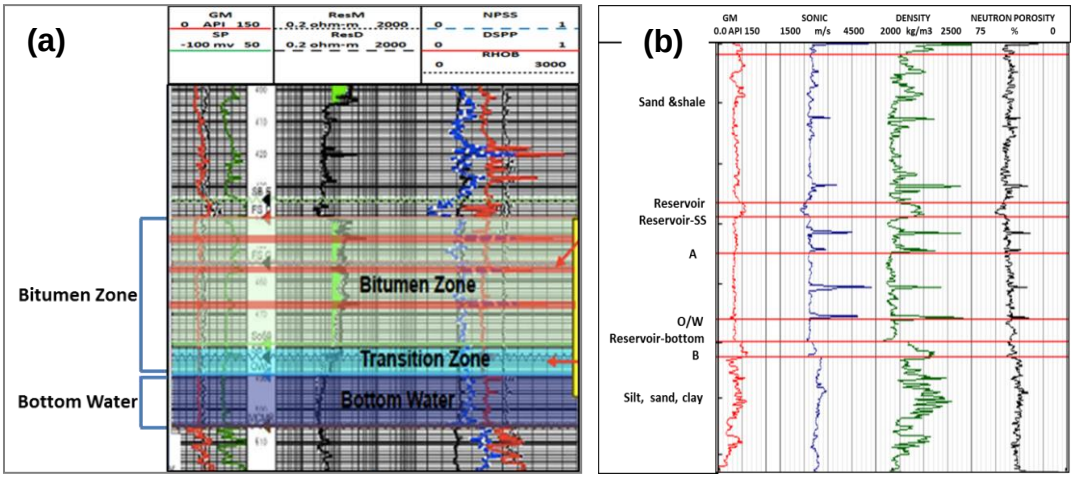

FIG. 1. (a) Typical logs of reservoir (from AER report) and (b) logs from well.

Inversion and AVO attributes analysis on P-wave data

Inversion and AVO attributes analysis helped to identify lithology and fluid changes inside the reservoir. An S-impedance vs P-impedance cross-plot is shown in Figure 2(a), which shows that the reservoir base has higher Zs/Zp. The cross-plot canceled out the effect of density (assuming that density has negligible changes). Therefore, it is the reciprocal of Vp/Vs which is higher at top of reservoir and lower at bottom of reservoir and they both follow an approximately linear trend.

Vp/Vs is also a good indicator of the sand and shale distribution. Based on the Greenberg and Castagna (1992) definition of different for commonly occurring lithologies, sand has slightly higher Vp/Vs than shale. Lower values of Vp/Vs which usually indicates saturation of hydrocarbon or water. If gas is present, the Vp/Vs is even lower than that for wet sands. Figure 2(b) shows a Vp/Vs vs P-wave impedance crossplot. Most of samples from the reservoir top (shale-sand contact, yellow and orange dots) are located in low impedance but high Vp/Vs zone while samples from the bottom of the reservoir (sand-shale contact, purple dots) are located in high P- impedance but low Vp/Vs zone. The crossplot also makes easier for us to identify the gas effects. If there is gas effect, it should locate at low P-wave impedance and low Vp/Vs zone (left bottom corner, marked by blue circle). Apparently, in our project reservoir, there are no gas effects.

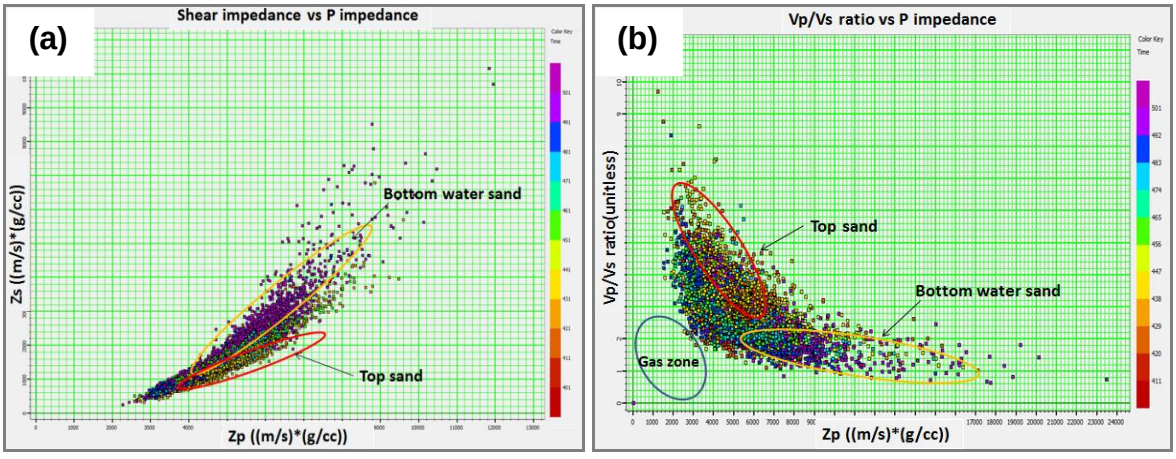

FIG. 2. (a) S-wave impedance vs P-wave impedance crossplot; (b) Vp/Vs vs P-wave impedance crossplot.

The top and bottom of the reservoir were identified by a cross-plot of inverted attributes. Lambda-Rho (LR) and Mu-Rho (MR) is another approach that helps to identify more details inside the reservoir. Mu-Rho (MR) vs Lambda-Rho (LR) cross-plot is shown in Figure 3. A λρ vs μρ crossplot may minimize the effects of density and help to interpret the λ and μ attributes: The samples highlighted by yellow rectangle have negative λρ values, probably caused by noise. The red rectangle zone should be a potential gas zone with low λ but high μ. Since there are only few samples in this interval, it evidenced that there are no gas effects in the reservoir. This result is consistent with the production data. The convincing cluster patterns can be seen in this cross-plot. For example, the samples from the overlying shale are highlighted by the grey circle with low compressibility and low rigidity; samples from the reservoir top (sand) are highlighted by red ellipse with slightly higher incompressibility and rigidity; samples from the reservoir sand are highlighted by blue ellipse which show very low incompressibility and rigidity; samples from the bottom water sand are highlighted by yellow circle which show similar incompressibility as the top reservoir sand but slightly higher rigidity. LMR is an effective tool to predict lithology and fluid in the studied reservoir.

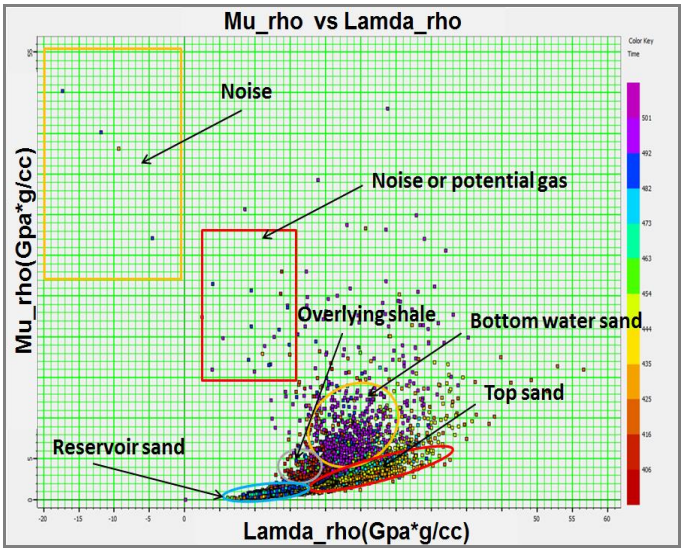

FIG. 3. Mu-rho vs Lambda_rho crossplot. The LMR crossplot helped to identity different litholigies and fluid changes of the reservoir.

PP- PS joint inversion

In this work, we also recorded and processed converted-wave data. Figure 4 shows post-stack PP-PS image registration. PS data has been transformed to PP time by picking the corresponding horizons on both datasets. Reservoir zone is highlighted by a yellow rectangle.

Joint PP-PS inversion can provide additional value and reduce risk or uncertainty in fluid/lithology discrimination and reservoir characterization. Figure 5 shows comparisons of S-impedance vs P-impedance cross-plots created from PP-PS joint version (a) and P-wave inversion (b). A cross-plot from PP-PS joint inversion shows the samples from the entire reservoir locate in four major zones. We can easily identify overlaying shale, reservoir top sand, reservoir sand and bottom water sand on the cross-plot while this distribution doesn't show on P-wave inversion cross-plot. The comparison validated that the information from S-wave data improved accuracy of prediction of lithology and fluid in the reservoir zone.

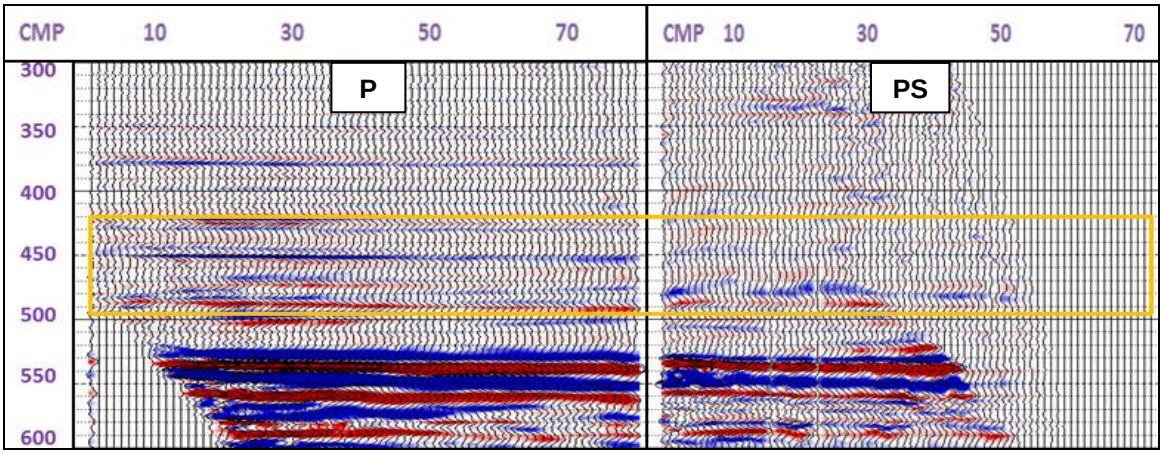

FIG.4. Registration of PP and PS data. Reservoir zone is highlighted by a yellow rectangle.

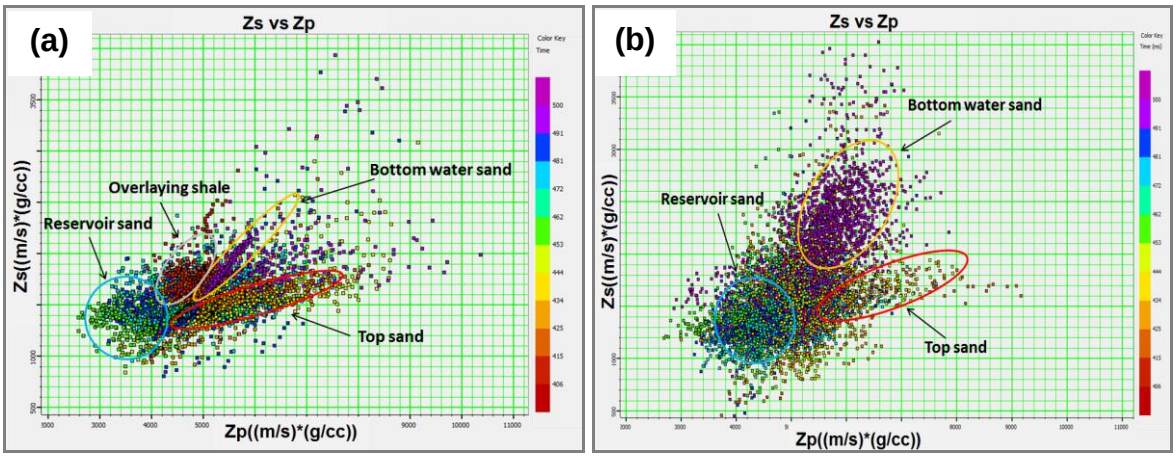

FIG. 5. Comparison of PP-PS joint inversion and P-wave only inversion. (a) Crossplot of S-impedance vs P-impedance inverted from PP-PS joint inversion; (b) crossplot of S-impedance vs P-impedance inverted from P-wave inversion.

Conclusions

Due to the advantage of VSP geometry, the hydrocarbon effects may be more visible on VSP data than surface seismic sections. In this work, we successfully applied VSP data analysis to predict rock properties and monitor production. Properties analysis showed no obvious gas effects in the studied interval which was validated by production data. PP-PS joint inversion added value to P-wave only interpretation. Inverted rock properties and their cross-plots, AVO Lambda-mu-rho analysis are effective tools to predict lithologies and hydrocarbon in the target reservoir. However, the lower resolution of the PS image and the distance of the well and VSP borehole as well as the absence of S-wave log may degrade the reliability of the detailed interpretation.

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