Beyond seismic stack: How rock physics inversion helps with horizontal oil well placement in Southern Alberta

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Summary

Seismic reservoir characterization is a method of geophysical interpretation that seeks to provide insight into subsurface properties and conditions through seismic amplitude analysis. Reservoir characterization is used to help with all stages of field development from well placement and completions design to time-lapse (4D) methods that monitor fluid migration and/or geo-mechanical changes due to production. AVO inversion is subset of seismic reservoir characterization whereby variations in seismic amplitude with offset are inverted for elastic properties. Rock physics provides the connection between these elastic properties and petrophysical parameters including porosity, lithology and fluid saturations. In this case study, we demonstrate how AVO inversion and rock physics inversion is used to optimize horizontal oil well placement in the Ellerslie formation in Southern Alberta using porosity, lithology and fluid prediction for reservoir quality assessment; Poisson's ratio and Young's modulus for drilling completions design; and rock physics inversion as a key means to improve horizon picking and structural interpretation. In particular, we show examples of how rock physics inversion improves the interpretation of key transitions in the stratigraphic sequence to steer well paths and the use of porosity and lithology volumes to predict well performance. The accompanying oral presentation will include additional examples of horizontal well trajectories overlying porosity, lithology and fluid saturations estimated from rock physics inversion. In addition, we will show statistical analysis comparing rock physics inversion results to data from dozens of horizontal wells drilled in the study area using the inversion results as a guide.

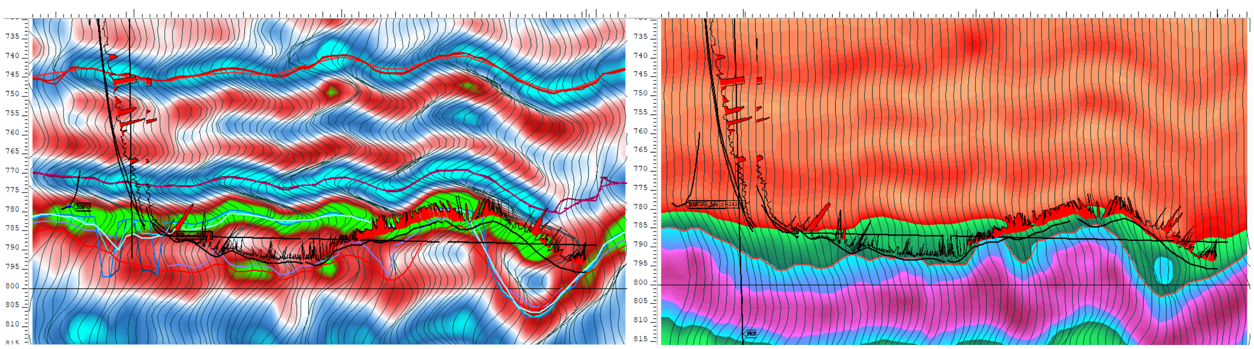

Figure 1: Comparison of well trajectory overlain on a seismic (left) and volume of lime (right) section.

Theory

This section provides a brief, high-level description of AVO inversion and rock physics inversion. An inverse problem involves calculating a model from a set of observations. In AVO inversion, we calculate the elastic model of the subsurface that produced the angle-dependent reflection amplitudes observed in seismic data. An Aki-Richards (1980) inversion kernel, a linearized version of the Zoeppritz equations, was used to compute the angle-dependent reflectivities. In this case, pre-stack partial angle-stacks were inverted simultaneously for changes in acoustic impedance, Vp/Vs and density. Angle-dependent wavelets and pre-conditioning of the input seismic data were rigorously tested through to inversion to determine the optimum inversion settings for any given dataset. It is of utmost importance that we achieve the most accurate and robust inversion result possible in order to ensure any subsequent interpretation is also as accurate.

The rock physics model is based on the work by Westang et al. (2009). It is a non-linear regression-based model that obeys physical bounds theory and honors single and multi-mineral fluid substitution theory. The rock physics model is given by

$$\frac{1}{M+M_0} = \sum_i (1-\varphi)\frac{v_i}{M_i+M_0} + \frac{\varphi}{M_{fluid}+M_0}, \qquad (1)$$

where M is an elastic (bulk or shear) modulus, φ is total porosity, v_i is the volumetric fraction of the ith mineral, M_i is the elastic (bulk or shear) modulus of the ith mineral, M_{fluid} is the elastic modulus of the fluid and M_0 is a regression parameter that allows local trends of the field affecting the moduli such as pressure, temperature, cementation or matrix composition to be captured. In the forward mode, this rock physics model is used to estimate elastic logs. In the inverse mode, the model is used to calculate petrophysical properties from elastic inversion results. In this case, the final rock physics volumes were total porosity, volume of shale, volume of carbonate and water saturation.

Method and workflow

This work stems from three studies undertaken over the last three years exploring the Mannville group with seismic data in Southern Alberta. The focus is to help optimize horizontal well placement within the Ellerslie formation.

The geologic setting of the Ellerslie formation in this area has substantial impact on interpretation. It is overlain by the high porosity Bantry shale of the Ostracod zone and is underlain by the Paleo unconformity, below which lies the Pekisko formation. Figure 2 contains a simple stratigraphic section of the area. These especially strong reflectors above and below the reservoir make interpretation on conventional stack data extremely difficult. The most porous and prospective sands are difficult to distinguish from the acoustically low Bantry and the acoustic high of the Pekisko obscures reservoir porosity. As such, the initial goals were concerned primarily with separating the Bantry shale from the Ellerslie and subsequently, to provide insight into the reservoir quality of within the Ellerslie itself.

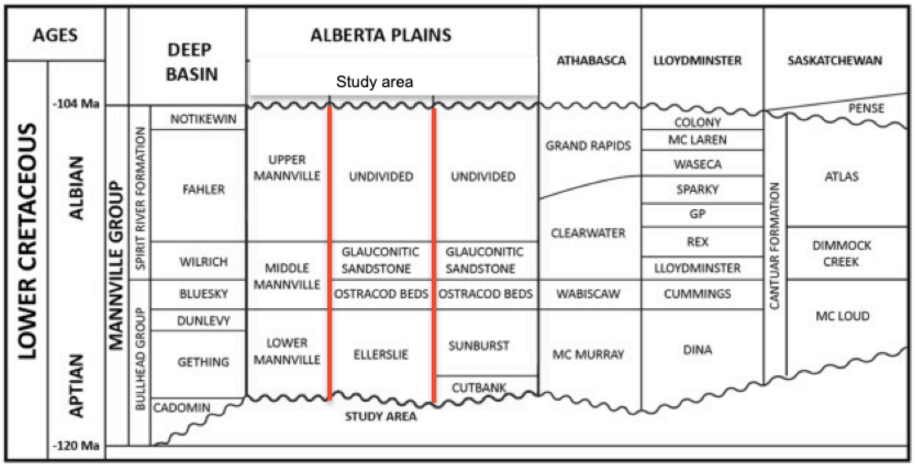

Figure 2: Stratigraphic section of Mannville Group. From Deschamps et al. 2017.

During this work, it became apparent that a key control over optimum well placement within the reservoir was to properly identify the underlying Pekisko formation. This unconformity controls both well trajectory and reservoir thickness for the Ellerslie. As an unconformity, the transition between these formations is abrupt and has a strong contrast, but the structure is so severe and discontinuous that the picking of this surface is extremely difficult on stacked sections. It was through the process of AVO inversion and rock physics analysis that the marked improvement in interpretability at this key structural control was identified. The elastic signature of the Pekisko formation is easily separable in elastic space and was readily identifiable in the inversion results. A carbonate mineral was not initially considered in rock physics modeling as it was not present in the original petrophysical model. A more detailed petrophysical model was created that included a carbonate mineral, allowing for the estimation of a more accurate rock physics model that explicitly includes a calibrated carbonate mineral as a third mineral constituent in order to provide direct rock physics insight into the mapping of the Paleo unconformity. The resultant rock physics model is shown in Figure 3 along with in-line section plots comparing a seismic stack to rock physics inversion results for effective porosity and volume of limestone. The effective porosity volume provides valuable insight into the variability of reservoir quality within the Ellerslie formation and the volume of lime resolves much of the ambiguity in the structural interpretation of the Paleo unconformity.

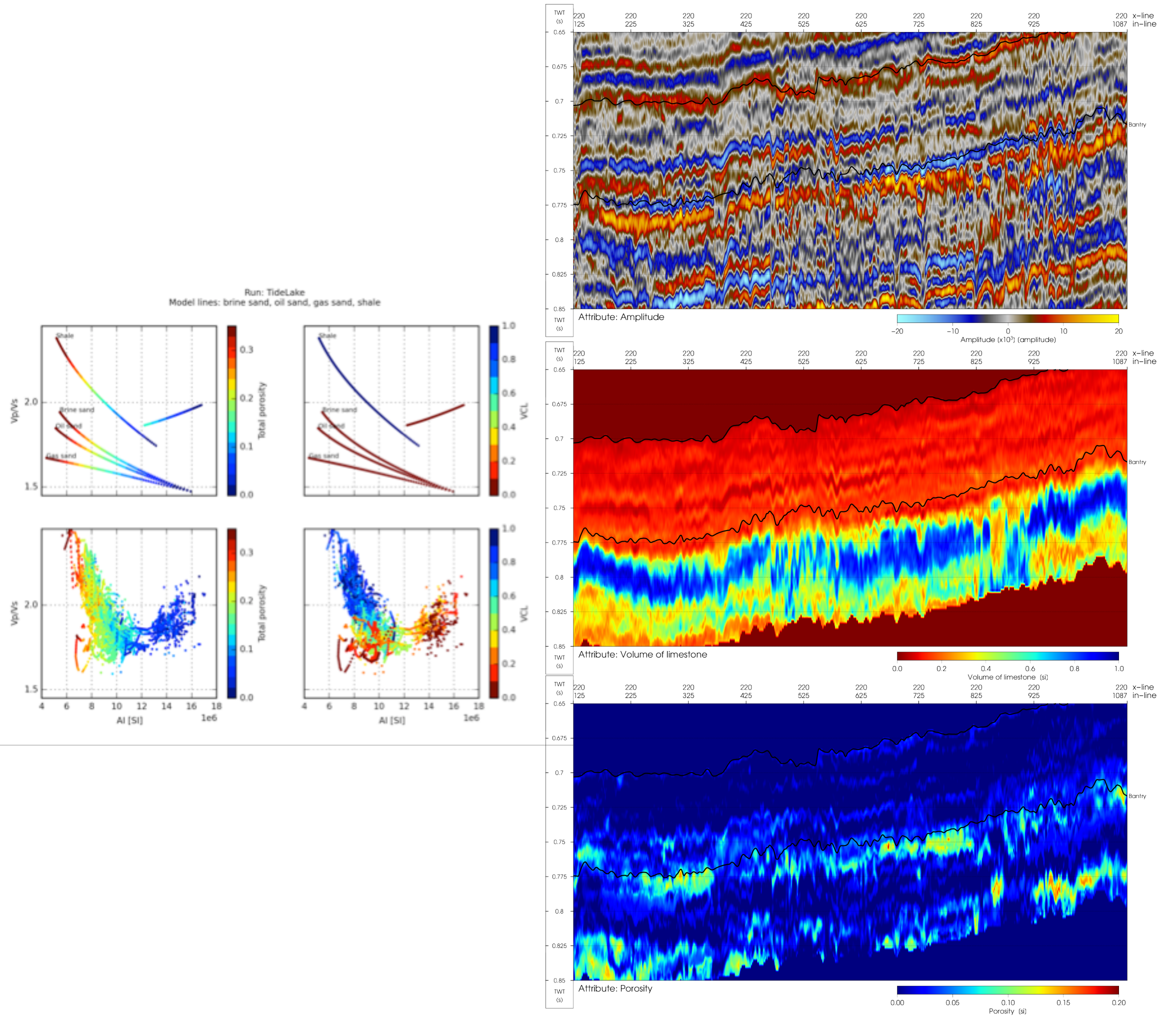

Figure 3: Rock physics model (left) and comparison along in-line of seismic stacked data, volume of lime and effective porosity rock physics inversion results (right).

Results, Observations, Conclusions

In this study, AVO inversion and rock physics inversion was critical as both a means to provide a quantitative assessment of reservoir quality in the Ellerslie formation and equally importantly, as a means to improve the overall stratigraphic and structural interpretation of the overlying and underlying units. The results are a primary driver in horizontal well placement. The improvements in interpretation and reservoir understanding are key in the exploration success in a mature target that was previously difficult to constrain with seismic stack data. Case studies such as these are important in providing insight into how seismic inversion and geophysics as a whole is still valuable and continuing to evolve in its use in the energy industry today.

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