Lithology and Fluid Prediction by Using a Cascade AVO Inversion Method: A Case Study of Bitumen Reservoir in Alberta's Oil Sands

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Summary

The Sunrise study area is located within the Athabasca oil sand region in Alberta, Canada. The deposits of oil sands are present in the Cretaceous McMurry Formation, which has a depth ranging from 125 to 200 meters. The primary method of recovery is the Steam-assisted Gravity Drainage (SAGD) process, in which high-temperature and pressure steam is injected to form a steam chamber. The success of this process depends on the identification of lithology and fluid distribution, including Muddy IHS and lean zones that affect the shape and growth of the steam chamber and reduce the efficiency of steam utilization.

The utilization of seismic inversion in the prediction of various elastic attributes, such as density, impedance, lambda-rho, and mu-rho, can provide insight into rock properties, particularly lithology and fluid composition. Analysis of dipole sonic wells through cross-plotting techniques in the study area indicates that shale or muddy IHS facies exhibit a higher density than the bitumen-rich sands in the surrounding area and can be differentiated through a density vs. acoustic impedance cross-plot (Figure 1). The lean zone can also be identified through its distinguishable characteristics on the fluid factor vs. acoustic impedance cross-plot (Figure 2). The enhancement of density estimate and fluid factor obtained from the elastic properties are vital in seismic inversion and have been recognized as critical goals in the study. The estimation of density and other elastic attributes through seismic inversion is challenging due to the variability in the composition and thickness of unconsolidated sand, mud layers, and fluid combinations. The precision of the inversion results is contingent upon several factors, including the quality of the seismic data, the utilization of a geologically representative low-frequency model, the implementation of a localized wavelet, objective-oriented data conditioning, and an optimized inversion workflow.

In this study, a cascade AVO inversion workflow is proposed to enhance the accuracy of the density and other elastic attribute estimations. The results show that the muddy IHS intervals and lean zones, with thicknesses greater than three meters, can be effectively distinguished from the density estimates and are in good agreement with existing and drilling well data.

Theory / Method / Workflow

The AVO(Amplitude versus Offset) pre-stack inversion is a commonly used technique for Canadian Oil Sands reservoir characterization to estimate subsurface properties from seismic reflection data, but it faces several challenges, including heterogeneity of the subsurface, Incorporation of prior information, seismic data quality, local minima, non-uniqueness of inversion results.

The cascade multi-step AVO pre-stack workflow mitigates the challenges of local minima and non-uniqueness in inversion by proceeding from low frequency to high frequency using different linear and non-linear inversion methods. The idea behind this approach is to first use a simple and robust low-frequency inversion method, such as a linear inversion, to estimate the large-scale subsurface parameters. This initial estimate provides a starting point for subsequent higher frequency inversions, which can be more complex and sensitive to the details of the subsurface rock properties.

The cascade multi-step AVO pre-stack workflow progresses from low frequency to high frequency, incorporating additional information and constraints at each step. For example, the next step may involve a non-linear inversion method that takes into account the non-linear relationships between the subsurface rock properties and the seismic amplitudes. The results from the non-linear inversion can then be used to refine the subsurface parameters estimated in the previous step.

By combining linear and non-linear inversion methods in a stepwise manner, the cascade multi-step AVO pre-stack workflow helps to overcome the challenges of local minima and non-uniqueness in the inversion. The results from each step provide valuable information and constraints for the next step, allowing the inversion process to converge towards a globally optimal solution. This workflow results in a more accurate and robust estimation of the subsurface parameters, which can be used to better understand the subsurface geology and reservoir properties.

Results, Observations, Conclusions

The results from the multi-step AVO pre-stack inversion cascade have shown that this method leads to a significant improvement in determining density and fluid factor, which are crucial factors in characterizing the heterogeneities (muddy IHS and lean bitumen sand) that impact steam conformance. The improved accuracy of this approach provides a more reliable foundation for fluid and facies classification and reduces the chance of misidentifying lithology and fluid heterogeneities in Oil Sands reservoirs. Additionally, current, and historical production data and ongoing development programs can be integrated for further analysis and improvement.

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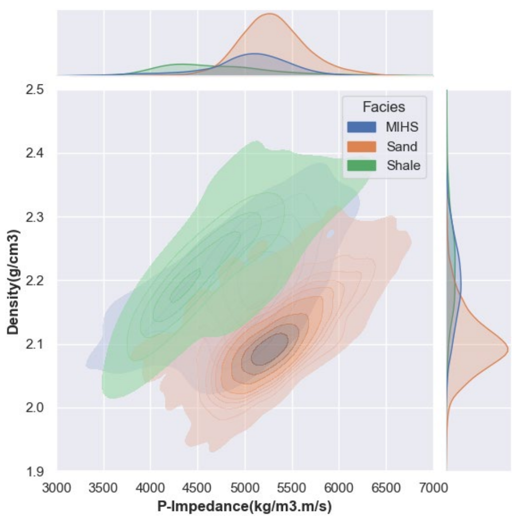

Figure 1, Cross plot of density vs acoustic impedance .

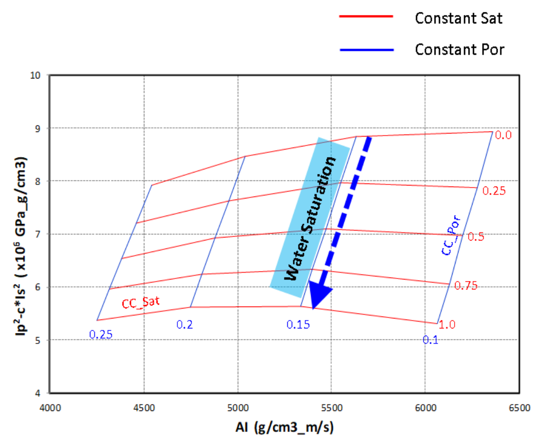

Figure 2, Rock physic template for the lean sand.

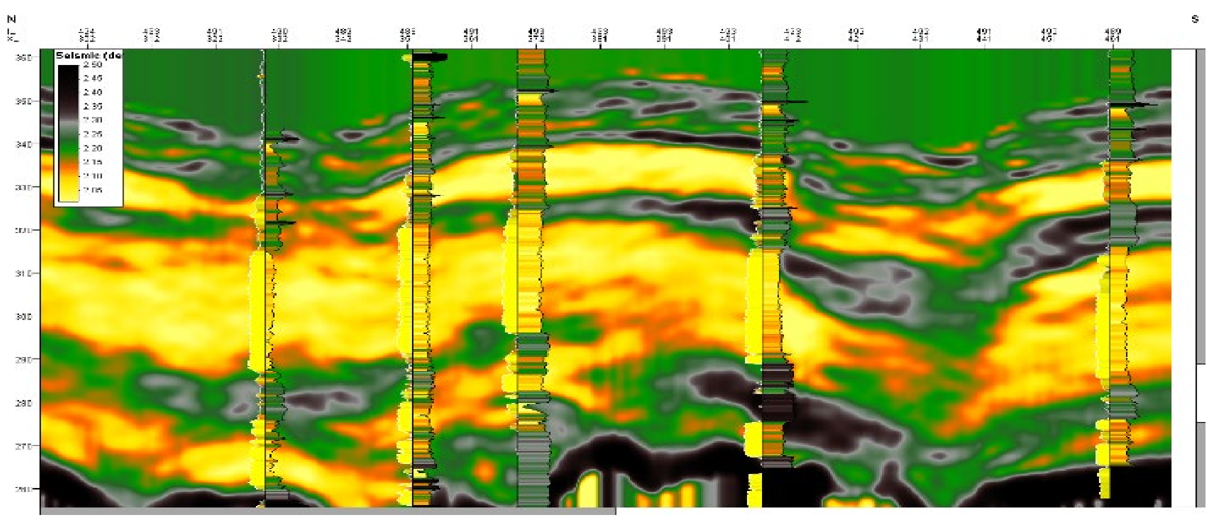

Figure 3, Density generated from cascade multi-step AVO pre-stack workflow