Direct Probabilistic Inversion: Adding back Geology into Geophysics through Probabilistic Inversion extended to accommodate Anisotropy in Quantitative Interpretation

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Summary

Within the application of seismic based Quantitative Interpretation (QI) methods to characterize reservoirs, there is a need to improve the accuracy, and resolution in estimates of key rock physics (seismic petrophysics) parameters.
The subsurface information obtained from standard AVO inversion is highly ambiguous as different lithologies and fluid configurations result in similar elastic responses. This is an intrinsic characteristic of the ill-posed non-uniqueness of the inversion problem that can be mitigated by integrating relevant and non-redundant information into the inversion process. Standard inversion techniques for example, are "unaware" of the lithological deposition, bed thickness distributions and petrophysical relationships such as lithofacies, effective porosity, and fluid fill within the reservoir. At the same time, reservoir characterization related decision-making for exploration and development well placement and risk analysis, also requires an increasing degree of assessment of the uncertainties associated with any predictions based on seismic QI.

Theory and Method

Bayesian inference solutions provide a framework where these issues can be addressed. However, in its standard formulation and given the size of typical seismic volumes it might be computationally prohibitive. In this study we show how, under reasonable assumptions, a high dimensional Bayesian inference problem can be reduced to a number of local low dimensional inference problems, reducing the computational cost of this solution. This enables the application of a general and flexible probabilistic framework for rigorous propagation of uncertainties where prior knowledge from multiple domains can be easily integrated in a Direct Probabilistic Inversion method (DPI).
This information is readily available from logs, core and geological studies that provide a model for specific ranges of elastic properties for target zone facies, average thicknesses and their petrophysical variation, stratigraphic position, as well as the presence and buoyancy relationships between gas, oil, and brine. Defining a set of rules based on this information will reduce the solution space dramatically. By contrast, in conventional deterministic seismic inversion algorithms all this prior information is difficult to integrate. Moreover, the correct propagation of uncertainties through the inversion is not possible.
These additional prior constraints of thicknesses, ordering etc. can also help resolve units that are below seismic resolution. In particular, the presentation case study will show how DPI can leverage this extra information to dramatically improve the resolution of thin, but elastically distinct organic layers. Not only does this lead to a better understanding of the lithofacies distribution, but it mitigates the ambiguity in isolating the target hydrocarbon sands, that are difficult to differentiate in deterministic inversion from very thin amplitude anomalies due to the organic layers.

Furthermore, the challenges presented by conventional reservoir sands encased in shales, often require the use of more complex approximations to model anisotropic AVO responses.
In order to implement an anisotropic extension to DPI we use Ruger's AVO approximation for VTI media as the forward modeling operator to compute the likelihood function in DPI. The benefits of this approach are two-fold. First, the model space is expanded from three (AI, Vp/Vs, density) to five elastic parameters which now includes the two weak anisotropy Thomsen parameters δ and ε. This provides an opportunity for resolving elastic ambiguities that might not be resolved by using only three isotropic parameters. Secondly, the use of a more complex AVO approximation that accounts for common anisotropic effects helps to avoid the misinterpretation of hydrocarbon (HC) related AVO signatures, which might result from the false positive effect of overlaying anisotropic shales above water-saturated sands.
Anisotropic DPI addresses these challenges within a probabilistic framework that provides higher vertical resolution than deterministic AVO inversions. Moreover, DPI integrates a priori geological information, like average thicknesses and/or stratigraphic ordering rules which reduces the solution space to only the stratigraphic relationships that can be supported by the geological deposition expected in the area.

Results

The case study will demonstrate how the VTI DPI method can resolve false positive AVO hydrocarbon responses within the reservoir sand interval due to overlying VTI shales from offshore East Coast Canada. Well log data from the Bay du Nord area reservoirs was used to build a 1D model to illustrate and test these ideas. In this case, understanding the vertical heterogeneities within the Mizzen and Bay du Nord formations is a key factor in exploration success. The results show, that even in the case of very thin, almost indistinguishable lithofacies but with slightly different anisotropic parameters, DPI is able to predict the spatial distribution of these facies with relatively high confidence levels and more importantly resolve the overlying VTI shale false positive AVO inversion HC prediction error that led to drilling failure: compare figures 1a to 1b.

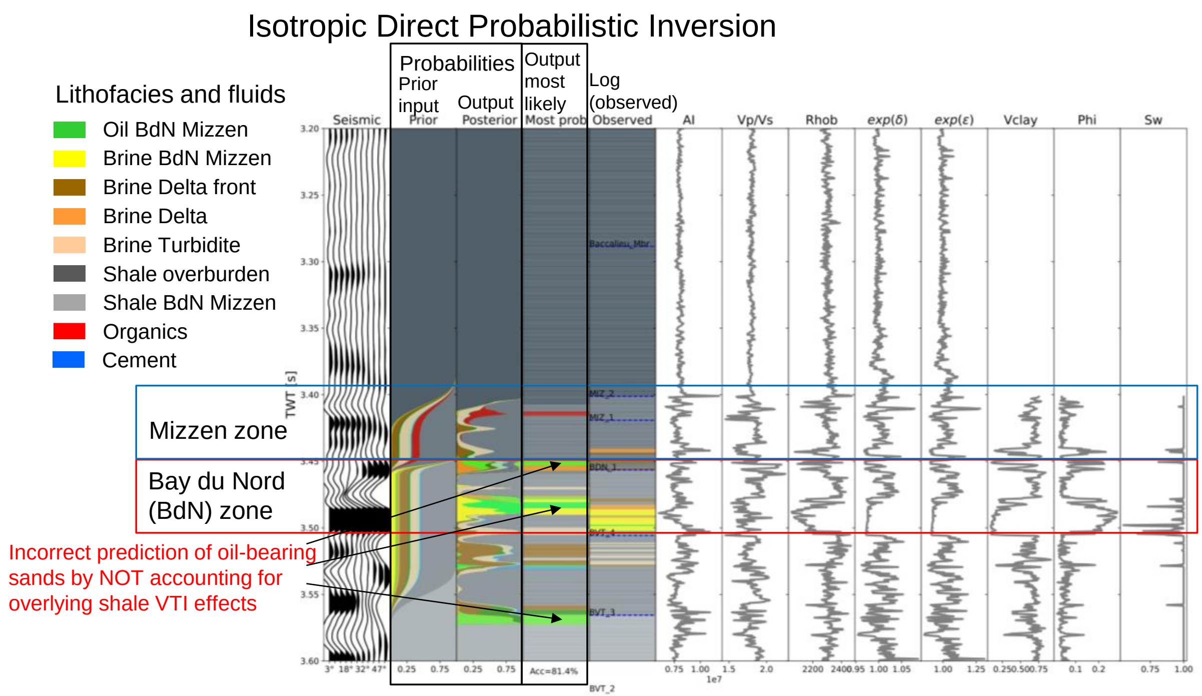

Figure 1a: Incorrect prediction of oil-bearing sands by NOT accounting for overlying shale VTI effects using Isotropic Direct Probabilistic Inversion.

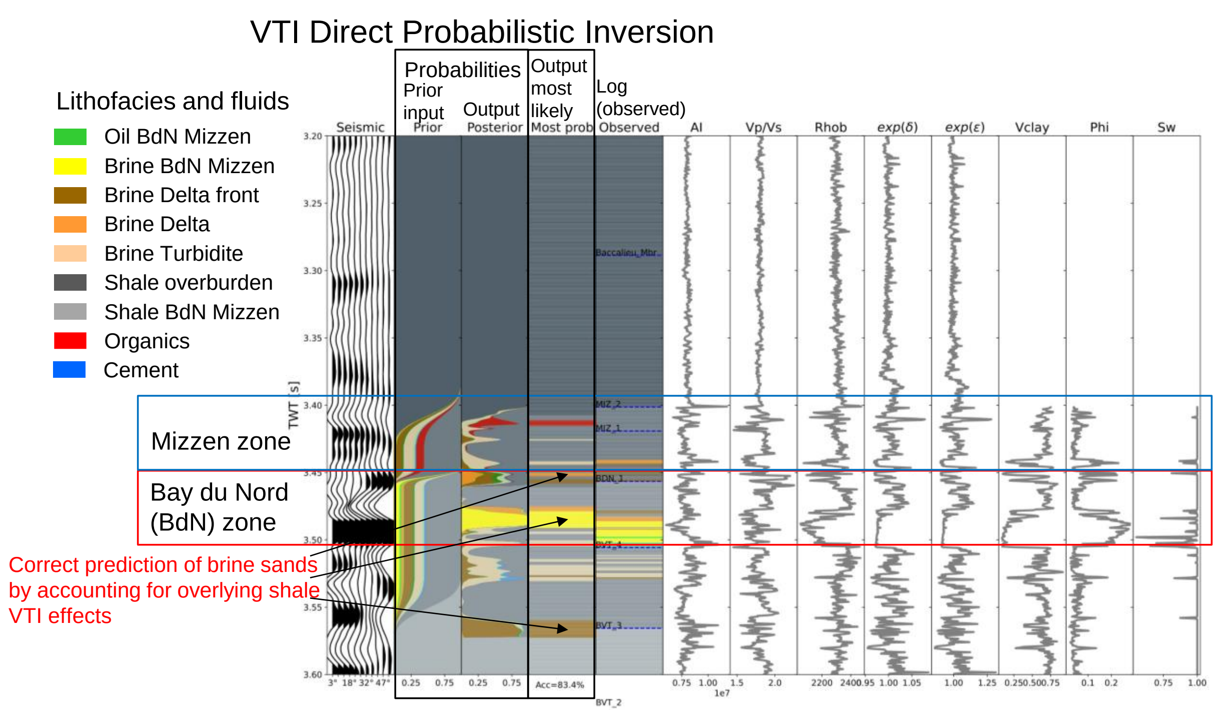

Figure 1b: Correct prediction of brine sands by accounting for overlying shale VTI false positive effects using VTI Direct Probabilistic Inversion.

Conclusions

The direct probabilistic inversion of anisotropic AVO data provides superior vertical resolution to what could be expected from a deterministic AVO inversion. Incorporating anisotropic effects during the inversion correctly accounts for changes in the AVO gradient resulting from a change in Vp/Vs and/or changes in the Thomsen VTI anisotropy parameters δ and ε. This differentiation is not possible when using isotropic formulations in which the presence of anisotropy resulted in an incorrect estimation of the gradient-related elastic parameters (Vp/Vs, shear-impedance, density, etc.).
Since the output of DPI are estimated probabilities for each facies at each depth, a more comprehensive statistical analysis can be performed for P10, P50 and P90 probabilities leading to a more in-depth interpretation and exploration risk analysis.

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