Bayesian approaches to estimating rock physics properties from seismic attributes

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Summary

Bayesian rock physics inversion refers to a set of probabilistic methods for the prediction of reservoir properties from elastic attributes, based on different statistical assumptions for the distribution of the model variables and different linear or nonlinear rock physics models. We have examined three Bayesian approaches using the well-log data at the Carbon Management Canada Newell County Facility, assuming Gaussian, Gaussian mixture, and non-parametric distributions of the rock physics variables. The solution is represented by the posterior distribution of rock physics parameters conditioned on elastic data. In this application, because the nonlinearity of the rock physics model is not strong and the data are approximately Gaussian distributed, the three results are similar, all capturing the trend of the actual logs. However, the Gaussian mixture model might be a more appropriate solution, owing to its efficiency and its ability to recognize the multimodality of the data. The proposed methods can be combined with elastic inversion to implement a two-step workflow of seismic reservoir characterization at the field, if we assume that the rock physics model calibrated at the well location is also valid far away from the well.

Method

Based on the well-log data of the CMC Newell County Facility (Lawton et al., 2019; Macquet et al., 2019) and the nonlinear rock physics model constructed at the well (Hu et al., 2022), we analyze three cases: 1) linearized rock physics model and Gaussian assumption of rock properties; 2) nonlinear rock physics model and Gaussian mixture assumption of rock properties; 3) nonlinear rock physics model and non-parametric distribution of rock properties.

Grana (2016) proposes a mathematical approach for the linearization of slightly nonlinear rock physics models, using first-order Taylor series approximations. If we assume that the model is Gaussian distributed and the data error is Gaussian with zero mean, then the posterior distribution is also Gaussian with analytical mean and covariance.

The Gaussian mixture model is a linear combination of Gaussian distributions. One of the advantages of Gaussian mixture models is the possibility to identify different seismic facies. According to Grana and Rossa (2010), we randomly sample the prior model space and apply the rock physics model to obtain the corresponding set of elastic properties. We then use these samples as a training dataset to estimate the joint distribution of rock and elastic properties. Then the conditional distribution is again a Gaussian mixture.

If the Gaussian assumptions are not in agreement with well-log data, a non-parametric approach should be adopted. Kernel density estimation is a non-parametric technique that allows us to estimate the probability distribution by fitting a base function at each data point including only those observations close to it. Because the joint and conditional distributions are numerically evaluated in a discretized domain for all the possible combinations of model and data variables, the method is computationally intensive.

Results

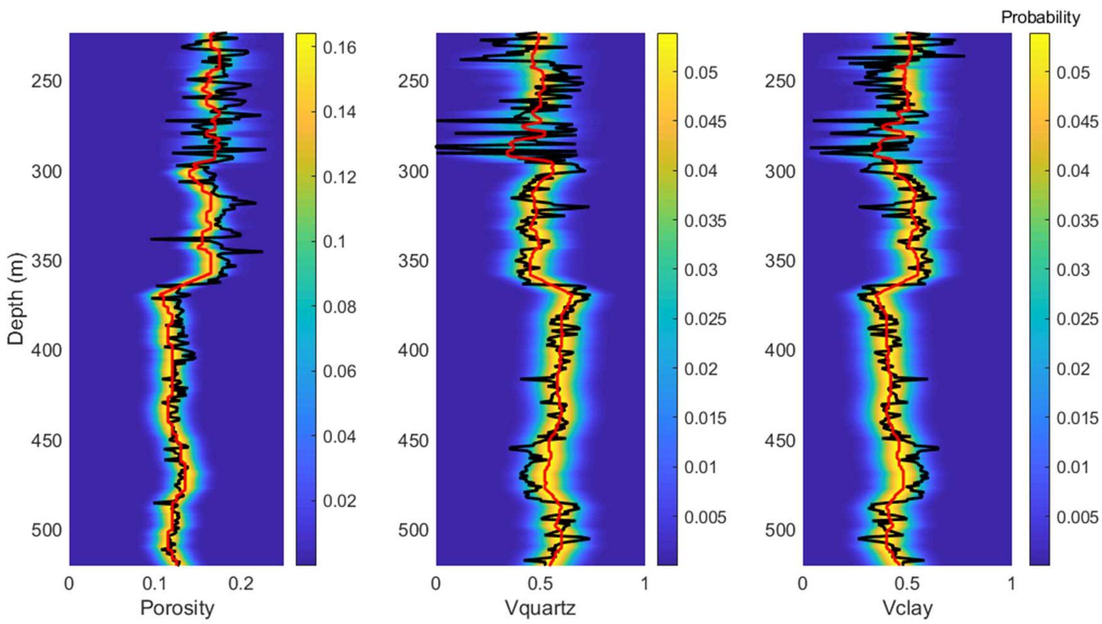

Figure1: Results of the Bayesian Gaussian mixture rock physics inversion. The background color represents the posterior distribution, and the solid red curves represent the maximum a posteriori prediction. The solid black curves represent the actual well logs.

Acknowledgements

This work was funded by CREWES industrial sponsors and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 543578-19. The data were acquired through a collaboration with the Containment and Monitoring Institute, Carbon Management Canada. The first author was partially supported by an SEG scholarship.

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