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Bayesian seismic-petrophysical inversion for rock and fluid properties and pore aspect ratio in carbonate reservoirs

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Introduction

Seismic characterization of carbonate reservoirs is a challenging task due to the complex structure of carbonate rocks, where the seismic response is affected by multiple factors such as pore volume and shape, as well as changes in mineralogy due to dolomitization and silicification. Hence, the prediction of petrophysical properties from seismic data is often uncertain. For this reason, we propose a statistical inversion method for the estimation of rock properties, where we combine Bayesian inverse theory with geophysical modeling. The geophysical model aims to compute the seismic response based on the rock and fluid properties and pore structure of the carbonate rocks, and it includes rock physics and AVO models for the seismic response. The Bayesian formulation allows for the solution of the associated inverse problem by computing the posterior distribution of rock and fluid properties and pore structure of the rocks conditioned by the measured geophysical data. The novelty of the proposed method is that the rock physics model can be any petroelastic relation, without requiring any linearization.

Method and/or Theory

We present a Bayesian inversion method for the estimation of petrophyscal properties. In this work, for applications to carbonate reservoirs, we combine Berryman's self-consistent inclusion model, the Aki-Richards approximation and Gasmann equation to compute elastic and seismic responses of rocks with known petrophysical properties. The Bayesian inversion method is based on a two-step approach: first the seismic inversion is performed and then the petrophysical inversion is applied. Because each inversion step is formulated in a Bayesian setting, the result of each step is a statistical model. For Bayesian seismic and petrophysical inversions, we combine the two probability distributions, the probability of elastic properties from seismic AVO inversion and the probability of petrophysical properties from rock physics inversion, to obtain the posterior distribution of petrophysical properties conditioned on seismic data. The statistical model assumes that the prior probability distribution of the model variables is a Gaussian mixture model such that distinct petrophysical characteristics can be associated with geological or seismic facies. The result of the proposed inversion is the most likely reservoir model of rock and fluid and pore geometry parameters, for example porosity, pore aspect ratio, and water saturation, and the uncertainty of the model predictions.

Results and Conclusions

The method is demonstrated and validated on synthetic and real examples. We generate a set of synthetic well logs using geostatistical simulations and invert the corresponding synthetic seismic trace to validate the inversion method. We also apply the proposed method to a real dataset, including well log and seismic data. The real data are from a carbonate reservoir with partial oil saturation in a pre-salt region of the Santos basin, offshore Brazil. We first apply the inversion to the seismic traces measured at the locations of two wells and then to the 2D seismic section. Applications show that the method allows finding accurate estimates of petrophysical properties at the well locations. The larger errors for saturation are possibly due to the limited variability of the saturation in the training data as well as the low sensitivity of seismic data to partial saturation. The aspect ratio estimated in the inversion is a valuable parameter for reservoir model interpretation, forecasting, and development.