Predicting, sampling, or optimizing the spatial distribution of petrophysical properties from seismic data

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Geophysical measurements are commonly used to predict rock and fluid properties in hydrocarbon reservoirs. The physical models that link the reservoir properties to their geophysical response are generally known. Therefore, the estimation of the properties of interest from the geophysical measurements is a mathematical inverse problem. The solution is not unique due to the noise in the measurements, the low resolution of the data, the approximations in the physical models, and the natural variability of the petrophysical properties. Deterministic and statistical approaches have been proposed in the literature. Statistical methods aim to predict the most likely solution as well as quantify the uncertainty. Such methods include several algorithms to predict the probability density functions of the properties of interest, to sample their spatial distributions, and to stochastically perturb and optimize the most likely values based on the mismatch between predictions and observed data. We discuss and compare stochastic methods for the prediction of the probability distribution of petrophysical properties conditioned by seismic data and the generation of multiple realizations of the petrophysical models with spatially correlated values. The implementation of these methods offers multiple options including the linearization of the geophysical forward models, the use of Gaussian approximations for different rock types, and additional spatial constraints in the geostatistical realizations imposed through spatial correlation functions for continuous properties and Markov chain transition matrices for discrete properties. We also discuss the quantification of the uncertainty for different statistical methods and its assessment compared to analytical solutions in the linear case and to numerical solutions obtained by Monte Carlo acceptance/rejection sampling for the non-linear case. We present synthetic and real examples at the well locations and along 2D seismic sections.