Probabilistic inversion with a facies dependent rock physics model

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Introduction

Prediction of lithology/fluid classes, petrophysical properties and elastic attributes subsurface given seismic observations is an inverse problem of utmost importance. A probabilistic workflow for assessment of these variables together with the associated uncertainty based on Monte Carlo simulation with lithology/fluid dependent rock physics models, extending Rimstad et al. (2012), is presented

Model

The main objective is to predict lithology/fluid classes κ, petrophysical properties r and elastic attributes m, given seismic observations d. We operate in a Bayesian framework, and assess:

$$p(\kappa|d) = const \times \int p(d|m)\, p(m|r,\kappa)\, p(r|\kappa)\, d(r,m) \times p(\kappa),$$

where κ follows a first order Markov chain to honour gravitational sorting, $p(d|m)$, $p(m|r,\kappa)$ and $p(r|\kappa)$ are, respectively, the seismic, rockphysical and petrophysical Gaussian likelihood functions. We assume a linear rock physics model:

$$[m|r,\kappa] = \mu_{m\vee\kappa} + B_\kappa (r - \mu_{r\vee\kappa}) + \epsilon_{r\vee\kappa},$$

where $\epsilon_{r\vee\kappa}$ is a Gaussian error term. Here, $\mu_{m\vee\kappa}$ and $\mu_{r\vee\kappa}$ are vectors with the pointwise expectations switching according to the lithology/fluids for respectively m and r. The block-diagonal matrix B_κ includes the lithology/fluid dependent regression coefficients. The seismic likelihood model is defined by a linearized weak contrast approximation of the Zoeppritz equation.

Assessment of $p(\kappa|d)$ is done by Markov chain Monte Carlo (McMC) algorithm based on a Markov random field prior in 2D.

Results and discussion

The proposed methodology is demonstrated on a cross section from the Norwegian Sea (Avseth et al., 2016) based on three angle-stacks. The likelihood functions (Fig. 1). are empirically calibrated based on upscaled well logs. Note that the rock-physics are 2D surfaces mathematically defined for all porosities and saturations, however, only a subset of them are valid geophysically. Three distinct lithology/fluids are of interest; shale, brine sandstone and gas sandstone.

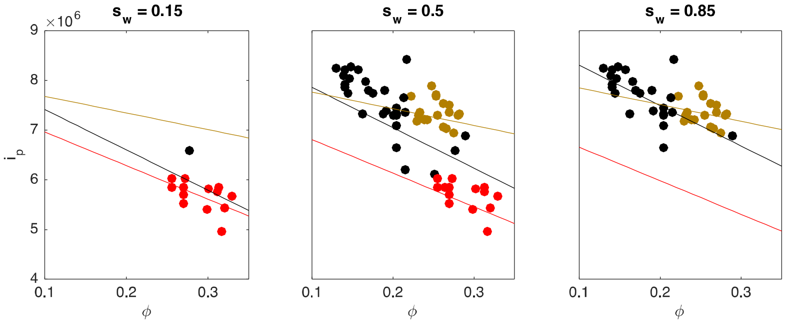

Figure 1: Upscaled calibrated rock physics model $[\log i_p|\phi,\kappa]$. The fitted regression lines are functions of porosity, and a fixed lithology/fluid and water saturation. Observed lithology/fluids (shale in black, brine sandstone in brown and gas sandstone in red) at the well location are indicated.

We obtain an acceptance rate of 17 % in the McMC algorithm. Results for the 2D section is displayed in Figure 2. Posterior continuous-valued properties are observed to be multimodal and skewed.

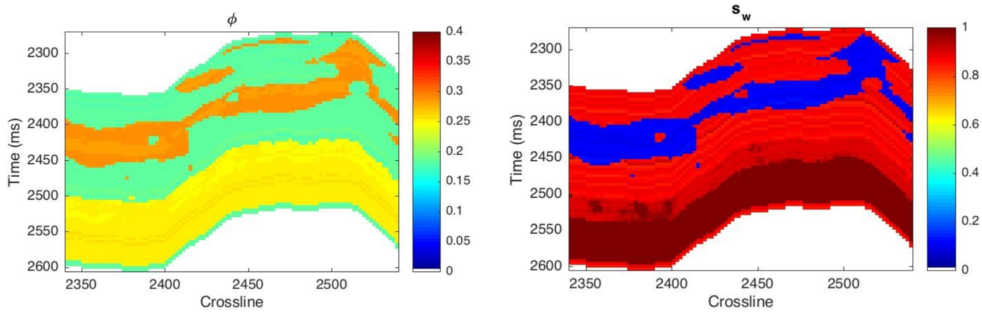

Figure 2: Posterior results 2D reservoir variables. Maximum posterior (MMAP) predictor lithology/fluids and MMAP predictors for ϕ and s_w.

Conclusions

Joint assessment of lithology/fluid, rock properties and elastic attributes given seismic observations is demonstrated on a case study from the Norwegian Sea. The model includes a lithology/fluid dependent likelihood function, where the rock physics model depends on the lithology/fluid classes.

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