Probabilistic inversion with a facies dependent rock physics model

Torstein Fjeldstad [a], Per Avseth [a]

[a] *Norwegian University of Science and Technology, Trondheim, Norway*
Contact email: torstein.fjeldstad@math.ntnu.no

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 on the work by Rimstad et al. (2012), is presented. The methodology is demonstrated on a Norwegian gas discovery.

Model

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

$$p(\boldsymbol{\kappa}|\boldsymbol{d}) = \text{const} \times \int p(\boldsymbol{d}|\boldsymbol{m})p(\boldsymbol{m}|\boldsymbol{r},\boldsymbol{\kappa})p(\boldsymbol{r}|\boldsymbol{\kappa})d(\boldsymbol{r},\boldsymbol{m}) \times p(\boldsymbol{\kappa}),$$

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

$$[\boldsymbol{m}|\boldsymbol{r},\boldsymbol{\kappa}] = \boldsymbol{\mu}_{\boldsymbol{m}|\boldsymbol{\kappa}} + \boldsymbol{B}_{\boldsymbol{\kappa}}\left(\boldsymbol{r} - \boldsymbol{\mu}_{\boldsymbol{r}|\boldsymbol{\kappa}}\right) + \boldsymbol{\epsilon}_{\boldsymbol{r}|\boldsymbol{\kappa}},$$

where $\boldsymbol{\epsilon}_{\boldsymbol{r}|\boldsymbol{\kappa}}$ is a Gaussian error term. Here, $\boldsymbol{\mu}_{\boldsymbol{m}|\boldsymbol{\kappa}}$ and $\boldsymbol{\mu}_{\boldsymbol{r}|\boldsymbol{\kappa}}$ are vectors with the pointwise expectations switching according to the lithology/fluids for respectively $\boldsymbol{m}$ and $\boldsymbol{r}$. The block-diagonal matrix $\boldsymbol{B}_{\boldsymbol{\kappa}}$ 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 $p(\boldsymbol{\kappa}|\boldsymbol{d})$ 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 a Norwegian Sea gas discovery (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.

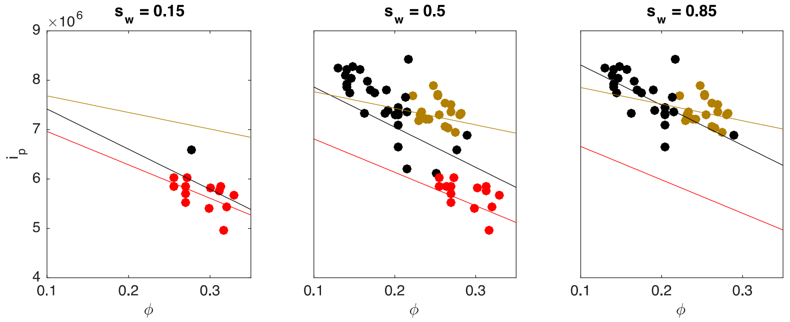

Figure 1: Upscaled calibrated rock physics model $[\log \boldsymbol{i_p} | \boldsymbol{\phi}, \boldsymbol{\kappa}]$. *The fitted regression lines are functions of porosity, and a fixed lithology/fluid and water saturation. Observed lithology/fluids (shale in black, brine sandstone in brown and gas sandstone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

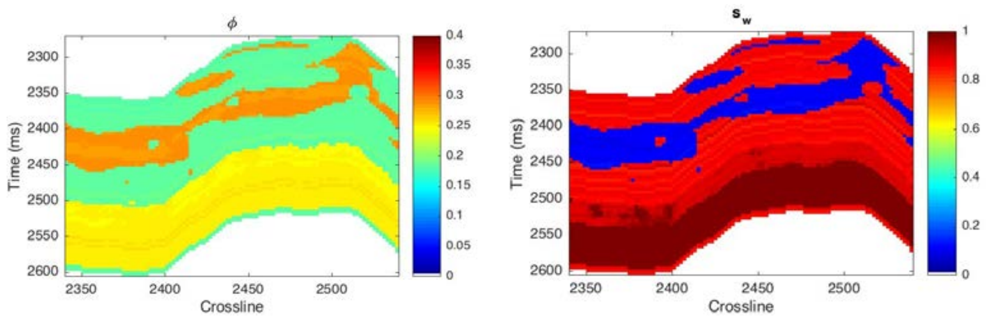

Figure 2: Posterior results 2D reservoir variables. Maximum posterior (MMAP) predictor lithology/fluids and MMAP predictors for $\boldsymbol{\phi}$ *and* $\boldsymbol{s_w}$.

Conclusions

Joint assessment of discrete lithology/fluid classes, continuous petrophysical properties, and elastic attributes given pre-stack seismic observations is demonstrated on a Norwegian Sea gas reservoir. The lithology/fluid dependent likelihood function allows us to obtain multi-modal predictions of petrophysical properties from the seismic data.

Acknowledgements

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References

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