Azimuthal seismic inversion for fracture weaknesses constrained by facies

Huaizhen Chen*, Jian Han and Kris Innanen
huaizhen.chen@ucalgary.ca

Abstract

A two-step inversion method of employing azimuthal seismic data to estimate fracture weaknesses constrained by fracture facies constraint is proposed. Firstly, we use a Bayesian Markov chain Monte Carlo (MCMC) algorithm to estimate EI of different incidence angles and azimuths, and predict fracture facies using the estimated EI. Secondly, we use the fracture facies to construct more accurate initial models of unknown parameters and use the estimated EI to obtain fracture weaknesses. Using noisy seismic data, we verify the robustness of the proposed inversion method.

Introduction

Subsurface natural fractures are important channels for oil and gas migration and storage. Using seismic data to implement predict the characteristics of underground fractures with high accuracy is of great significance.

Schoenberg and Sayers (1995) proposed the linear-slip model, in which two dimensionless parameters, the normal and tangential fracture weaknesses are presented to measure how fractures affect the displacement component perpendicular and parallel to the fracture plane. Fracture weaknesses become two important factors, which are used to indicate underground fractures.

Currently, lithology facies, are used to constrain seismic inversion for elastic parameters and reservoir parameters. Grana (2018) implemented the simultaneous estimation of lithofacies and reservoir parameters. Similar to the role of lithology facies in seismic inversion for reservoir characterization, we extract fracture facies from seismic data and involve the fracture facies as a constraint in the estimation of elastic parameters of isotropic background and fracture weaknesses.

Methods

Based on Bayesian theorem, we make probabilistic estimates of EI and fracture facies from azimuthally incidence-angle-stacked seismic data. The posterior probability distribution function, i.e. $P(\mathbf{m}, \mathbf{f}|\mathbf{d})$, is given by

$$P(\mathbf{m}, \mathbf{f}|\mathbf{d}) \propto P(\mathbf{d}|\mathbf{m}) P(\mathbf{m}|\mathbf{f}) P(\mathbf{f}), \quad (1)$$

We employ the MCMC algorithm to generate a few of acceptable results of EI and facies. The acceptance ratio is given by

$$r = \min\{1, \exp(-[E(\mathbf{m}^*) - E(\mathbf{m})])\}, \quad (2)$$

where $\mathbf{m}^*$ is the candidate, and

$$E(\mathbf{m}) = [\mathbf{d} - \mathbf{G}(\mathbf{m})]^T [\mathbf{d} - \mathbf{G}(\mathbf{m})] + \left(\frac{1}{2}\Delta\ln\mathbf{m} - s\Delta\mathbf{f}\right)^T \left(\frac{1}{2}\Delta\ln\mathbf{m} - s\Delta\mathbf{f}\right), \quad (3)$$

where s is a scale factor. Figure 1 reveals the relationship between the model vector $\mathbf{m}$ and fracture facies $\mathbf{f}$.

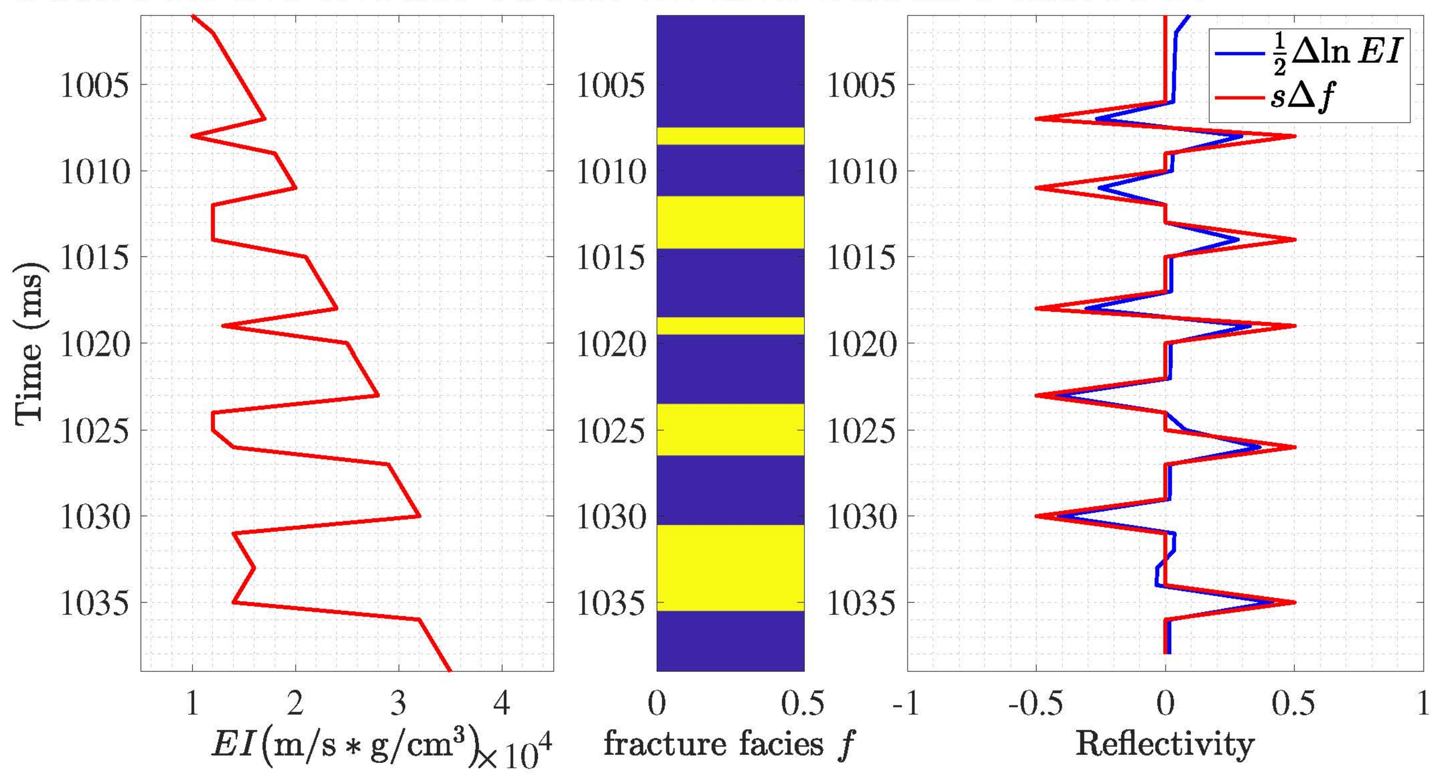

Figure 1: A layered model. The scale factor s is 0.5.

Using the estimated EI and fracture facies, we implement the inversion for elastic parameters and fracture weaknesses, and we employ model constraints constructed based on the estimated fracture facies to improve the accuracy of estimation of fracture weaknesses.

Results

We use synthetic data generated for a well log model to verify the robustness of the proposed inversion algorithm.

In Figure 2, we show curves of fracture weaknesses and the reference fracture facies.

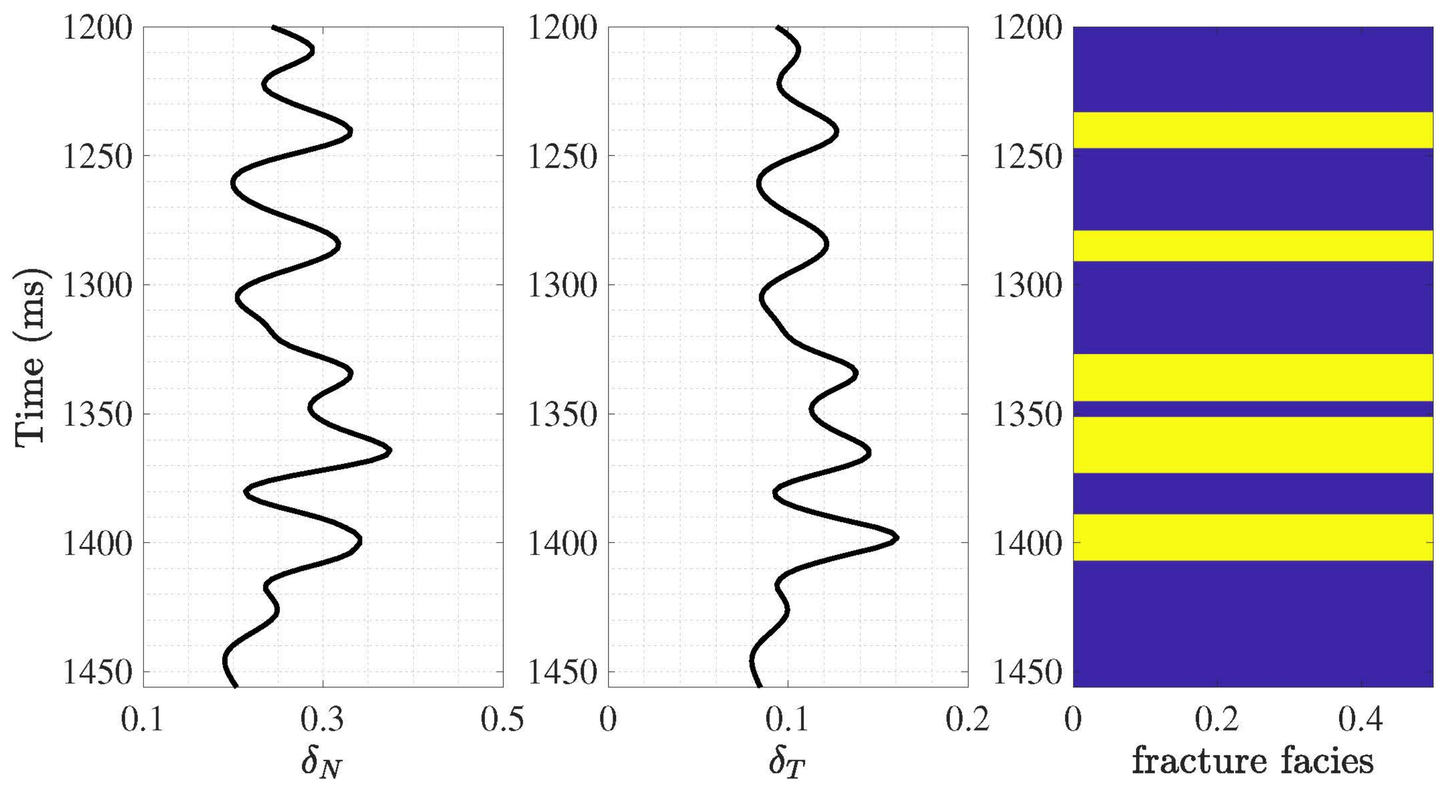

Figure 2: Curves of fracture weaknesses and the constructed fracture facies. We interpret the area where $\delta_T \geq 0.11$ as fractured reservoir and set f to 1).

Comparisons between the estimated fracture facies and the reference fracture facies are shown in Figure 3.

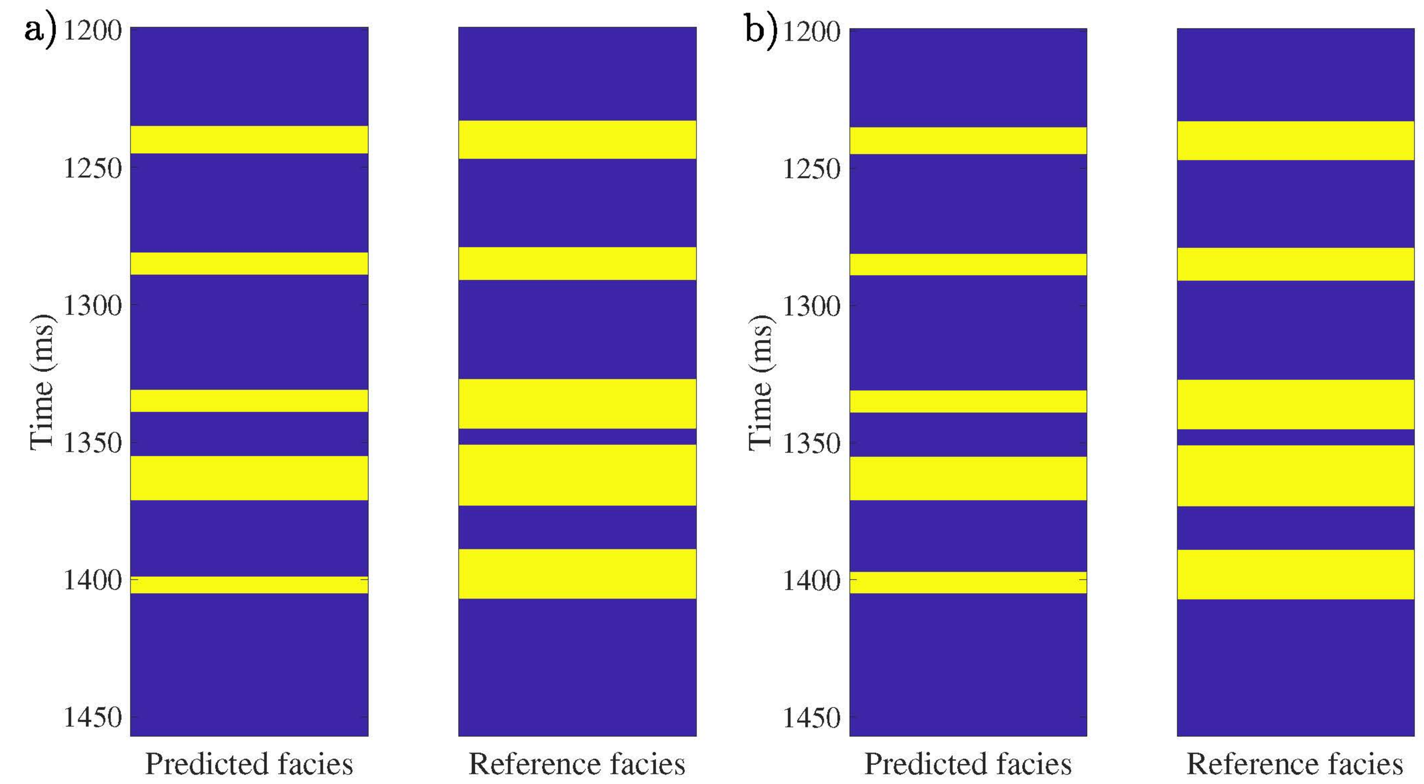

Figure 3: Comparisons between the estimated fracture facies and the reference fracture facies. a) S/N of 4; and b) S/N of 1.

Comparison between inversion results and true values of fracture weaknesses are shown in Figure 4

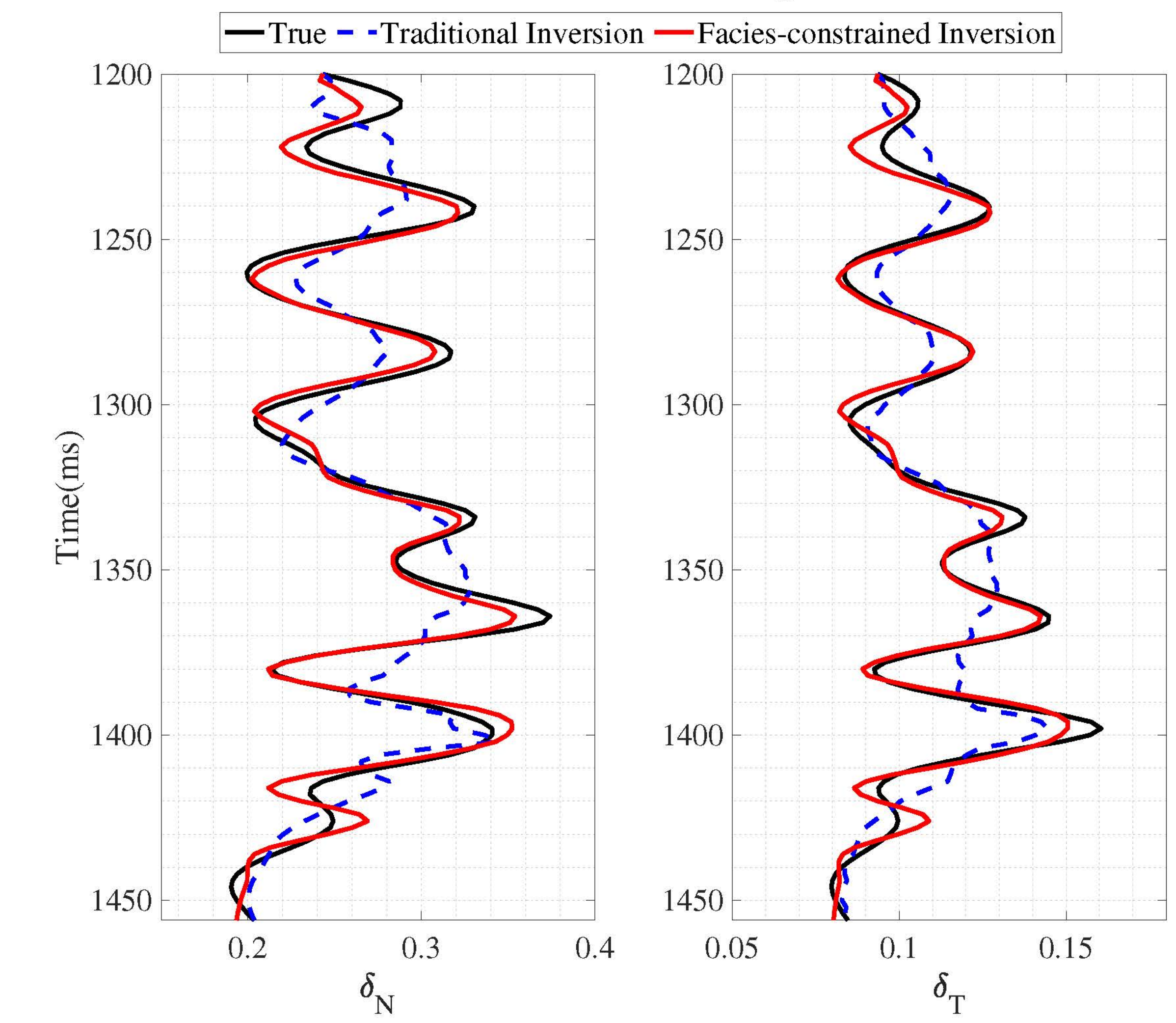

Figure 4: Comparisons between inversion results and true values of fracture weaknesses.

Conclusions

- A two-step inversion method is proposed to estimate tangential fracture weaknesses, in which fracture facies is employed as a constraint to improve the accuracy of inversion for fracture weaknesses.
- Test on noisy synthetic seismic data reveals that the inversion method proposed for estimating fracture weaknesses and constrained by fracture facies is robust.

References

- Grana, D., 2018, Joint facies and reservoir properties inversion: Geophysics, **83**, No. 3, M15–M24.
- Schoenberg, M., and Sayers, C. M., 1995, Seismic anisotropy of fractured rock: Geophysics, **60**, No. 1, 204–211.

NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience