Non-Linear Full-Waveform Inversion Using Prior Geological Knowledge*

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Abstract

One of the important challenges in seismic inversion is to resolve finer structures from band-limited seismic data. Reservoir-oriented full-waveform inversion has the potential to deliver high-resolution quantitative images and is a promising technique to obtain macro-scale physical properties of the subsurface (Ashnashari et al., 2012). Because full-waveform inversion accounts for the entire wavefield, the seismic modelling embedded in the inversion algorithm honors the full physics of wave propagation (Virieux and Operto, 2009). This makes the technique potentially an effective instrument for improving the characterization of complex geological settings (Plessix et al., 2010). Like for most geophysical application, prior information such as data collected in wells is available and should be used to improve the result. For this purpose we propose a new strategy for including prior geological knowledge in full-waveform inversion, which will ensure an even higher resolution in the final images. This new scheme does not constrain the inversion but uses blocky models drawn from the prior distribution as a starting point for the inversion. After an unconstrained inversion, the non-blocky result is re-interpreted in terms of the prior model. This can be seen as a Bayesian update in iterative non-linear inversion, this process is repeated after every iteration. This updated blocky model will be used as a starting model for the next iteration. This leads to a guided, nonlinear inversion process, where a geological scenario is proposed between two linear iteration steps. Given the prior probabilities and covariances, we are able to interpret the presence or absence of thin layers that otherwise cannot be detected using only band-limited seismic data. This scheme is demonstrated on a high-resolution synthetic model based on the Book Cliffs outcrop in Utah (USA).

References Cited

Plessix, R.E., 2009, Three-dimensional frequency-domain full-waveform inversion with an iterative solver: Geophysics, v. 74/6, p. 149-157.

Tetyukhina, Daria, Stefan M. Luthi, and Dries Gisolf, 2014, Acoustic nonlinear full-waveform inversion on an outcrop-based detailed geological and petrophysical model (Book Cliffs, Utah): AAPG Bulletin, v. 98/1, p. 119-134.

Virieux, Jean, and Stéphane Operto, 2009, An overview of full-waveform inversion in exploration geophysics: SEG, v. 74/6, p. 1-26.

Non Linear Full Waveform Inversion using Geological Prior Knowledge

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Objectives

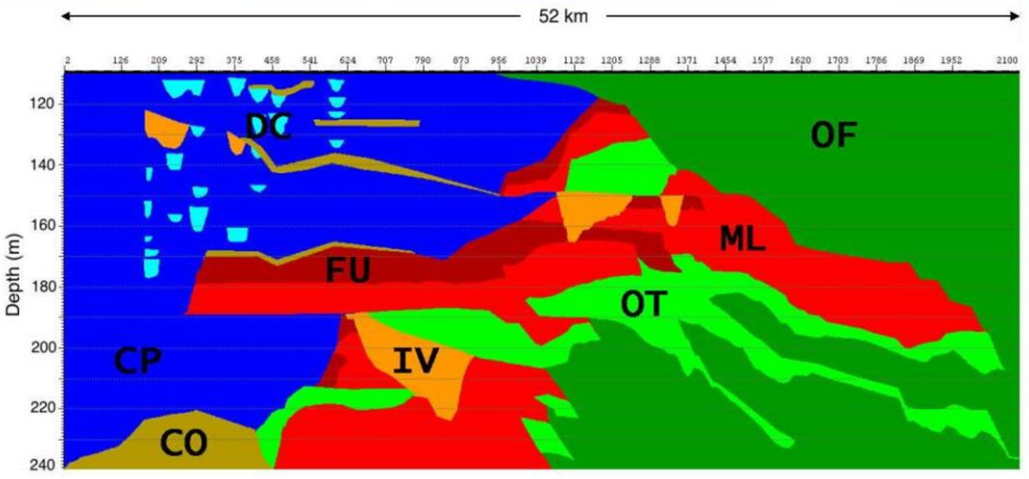
- Downscale the outcrop-based Book Cliffs reservoir model by Tetyukhina et al. (2014)

- Scenario Testing
  - Geological concept (scenario) as a starting point for the inversion.
  - Geological guidance to the inversion.
  - Improve the static models using parallel blocking process.
  - Assign probabilities to different scenarios.

Outline

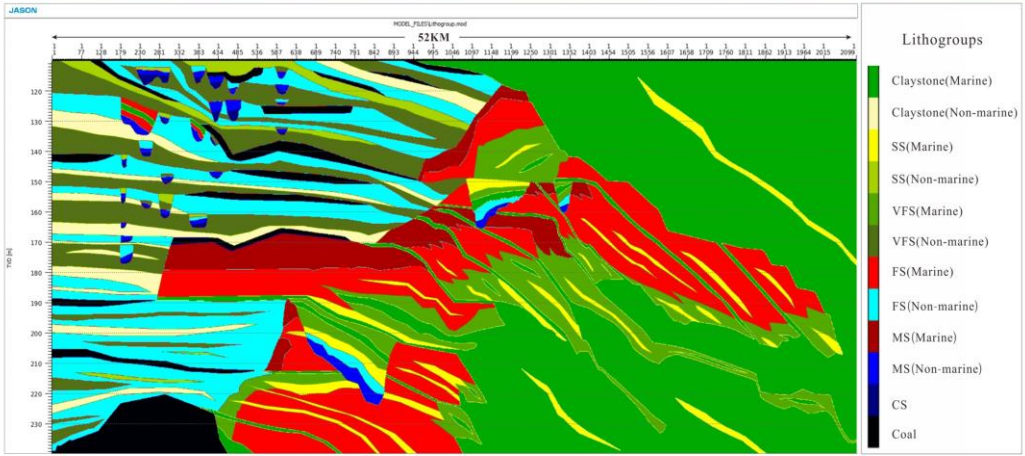
- **Downscale the Geological model**
- Scenario testing
- Synthetic demonstration

The Book Cliffs Model



CP: Coastal Plain; DC: Distributary Channels; CO: Coal; FU: Upper Shoreface; IV: Incised Valley; ML: Middle to Lower Shoreface; OT: Offshore Transitional; OF Offshore Mudstones

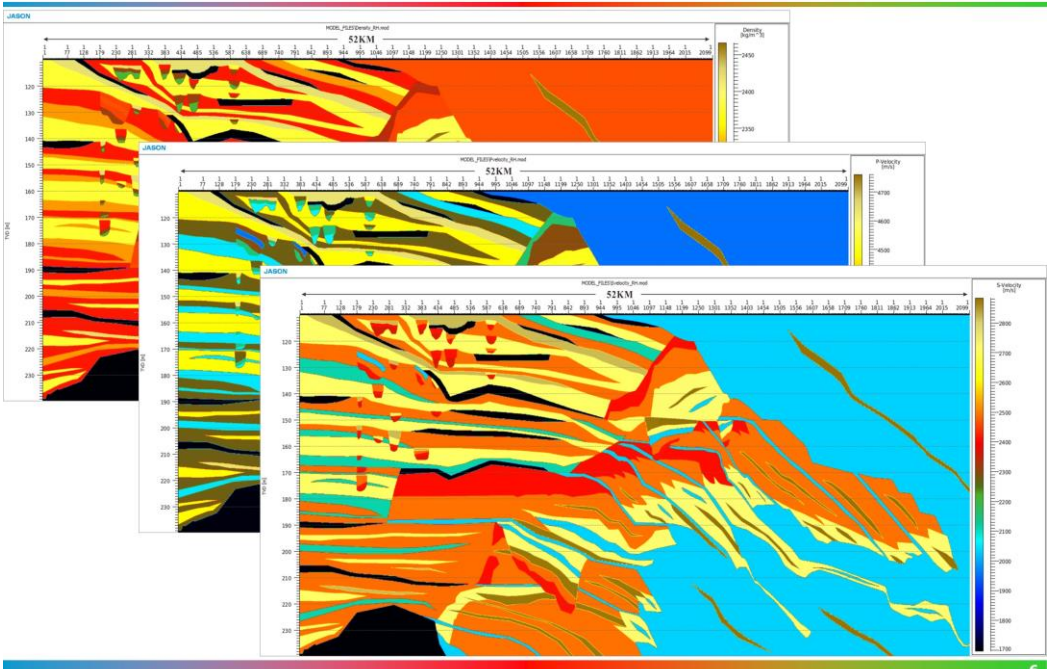
The Lithogroup Model



CS: Coarse Sandstone; MS: Medium Sandstone;
FS: Fine Sandstone; VFS: Very Fine Sandstone; SS: Siltstone

Presenter's notes: Here we can see that the sand unit has been divided into smaller units by the existence of claystone which is very important. Also the interfingering has been added in the parasequence which we believe it is a very good stratigraphic trap for hydrocarbon reservoirs.

The Resulting ρ/Vp/Vs Models



Presenter's notes: The lithogroup model then will be populated with the different properties.

Outline

- Downscale the Geological model
- **Scenario testing**
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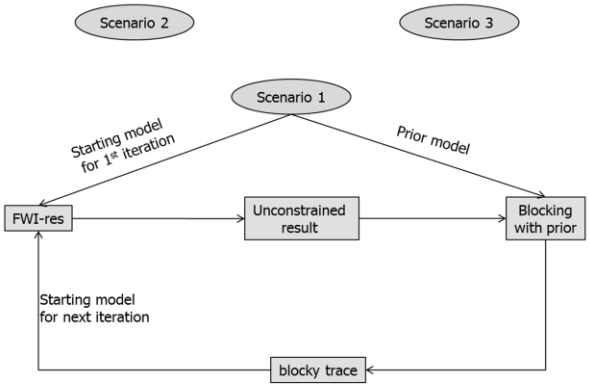
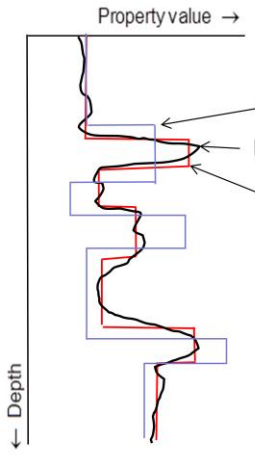
Testing Geological Scenarios



- We use the geological knowledge e.g. from logs to draw starting models for the inversion, but then let the solution evolve, unconstrained by a forced parameterisation.
- After inversion the result can automatically be blocked as a squared log in terms of the geological scenario. This will then be used as the starting model for the next iteration.

Blocky vs. Unconstrained Representations



Prior model $\underline{m}_{prior}$

Unconstrained inversion result κ_{inv}

Best fit blocky model, based on a layered geological scenario with prior probabilities κ_{bl}.

This becomes the starting model for the next iteration.

Outline

- Downscale the Geological model
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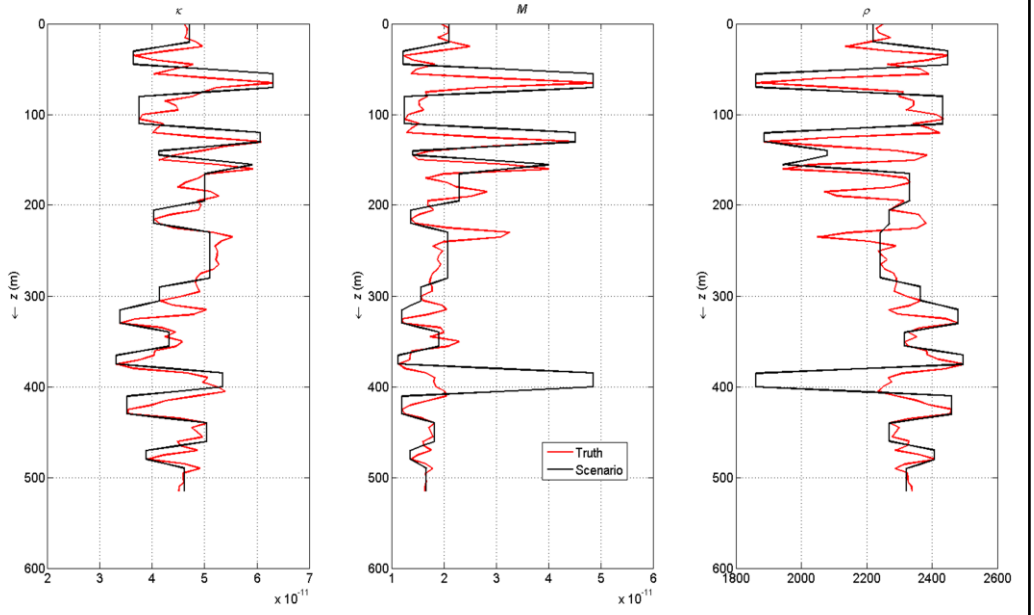
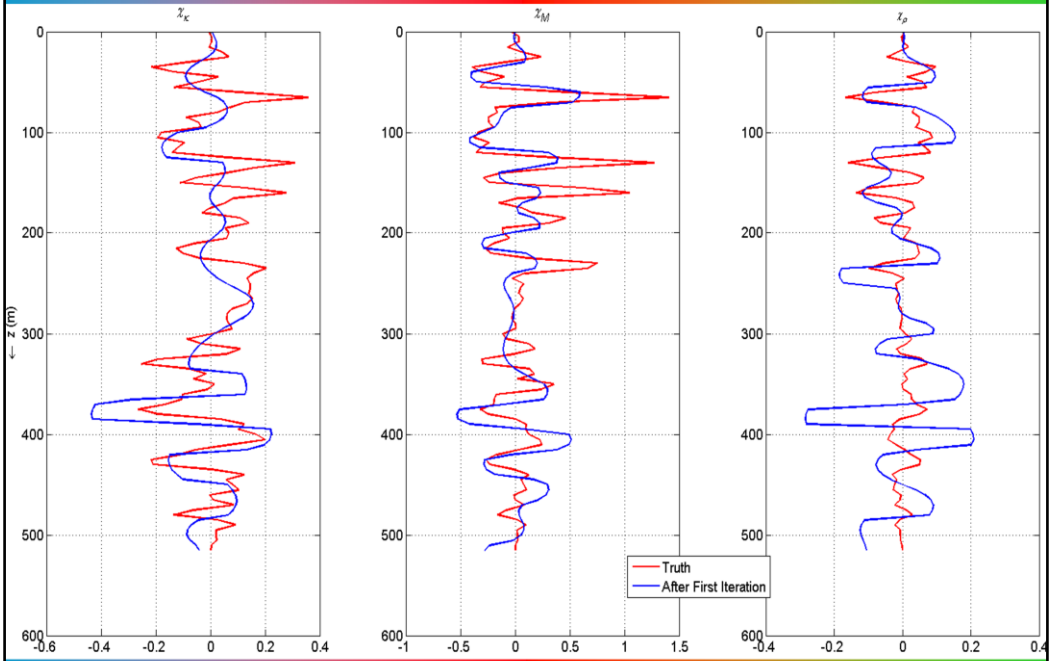
Scenario Building

- Building predictive static models occurs on the basis of geological knowledge (well logs, seismic data, interpretations, models)
- The static models include spatial variations in lithology
- Static reservoir models are improved through the analysis of dynamic data – an iterative process.
- This approach depends heavily on the quality of the static models.

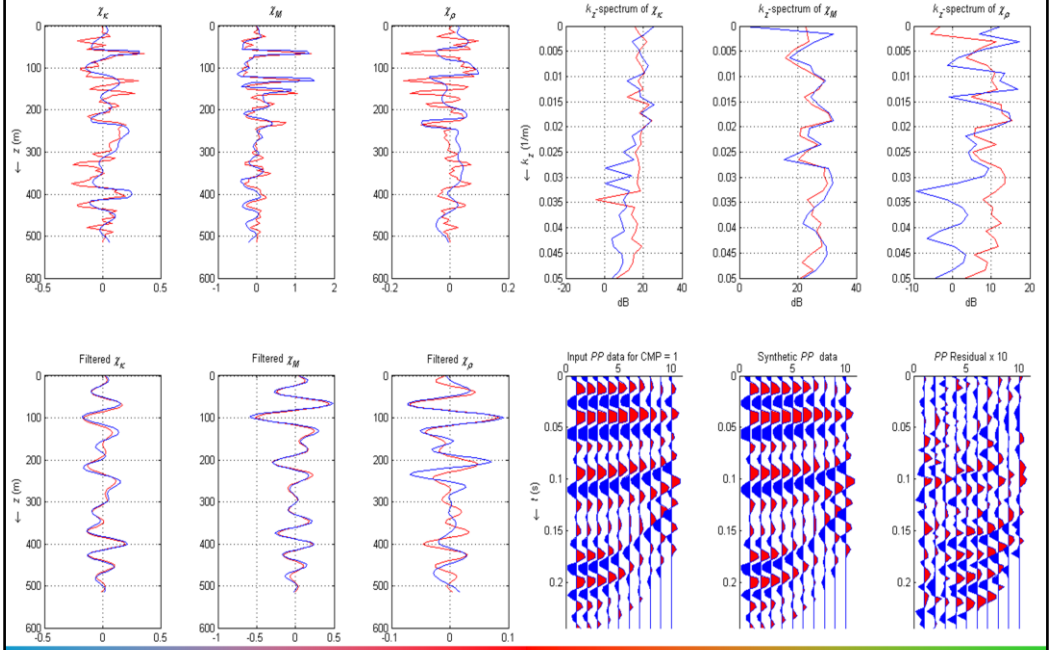
Example of a Scenario



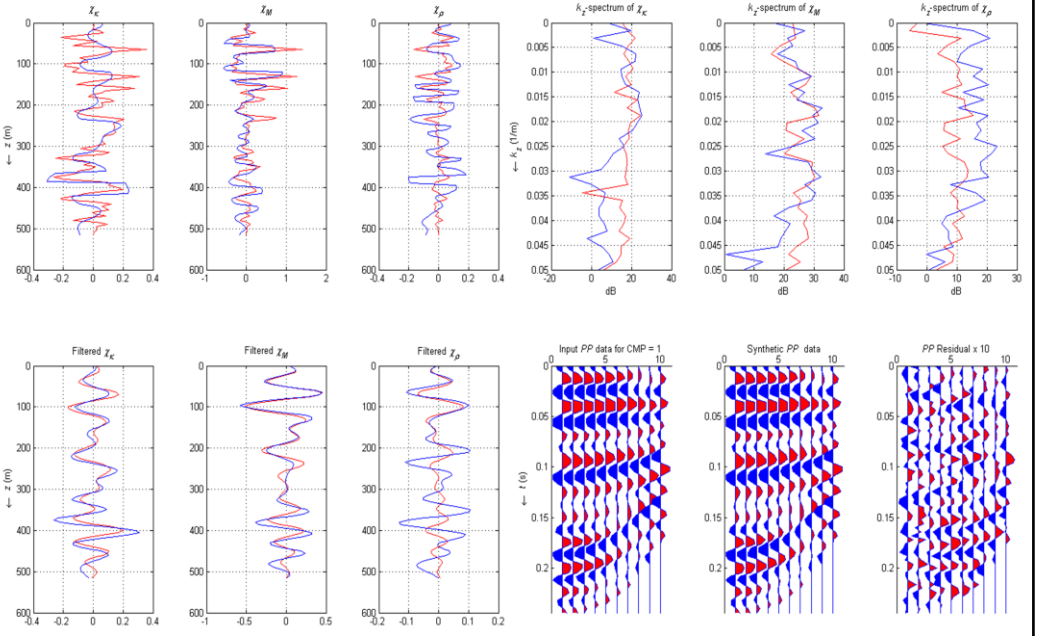
After the First Iteration



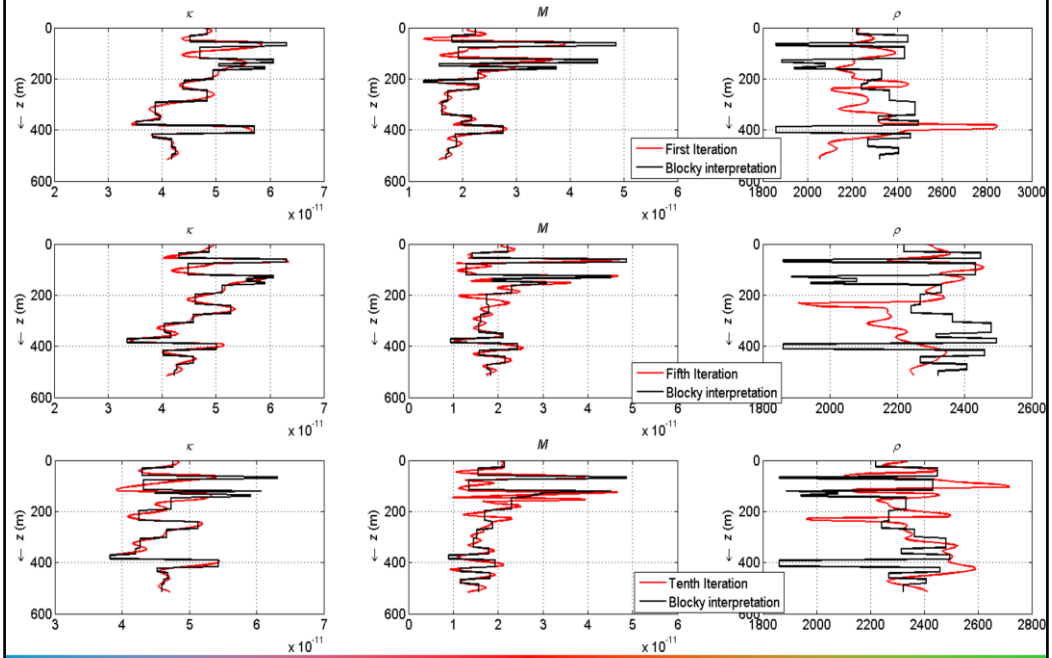
Inversion Results for Scenario I



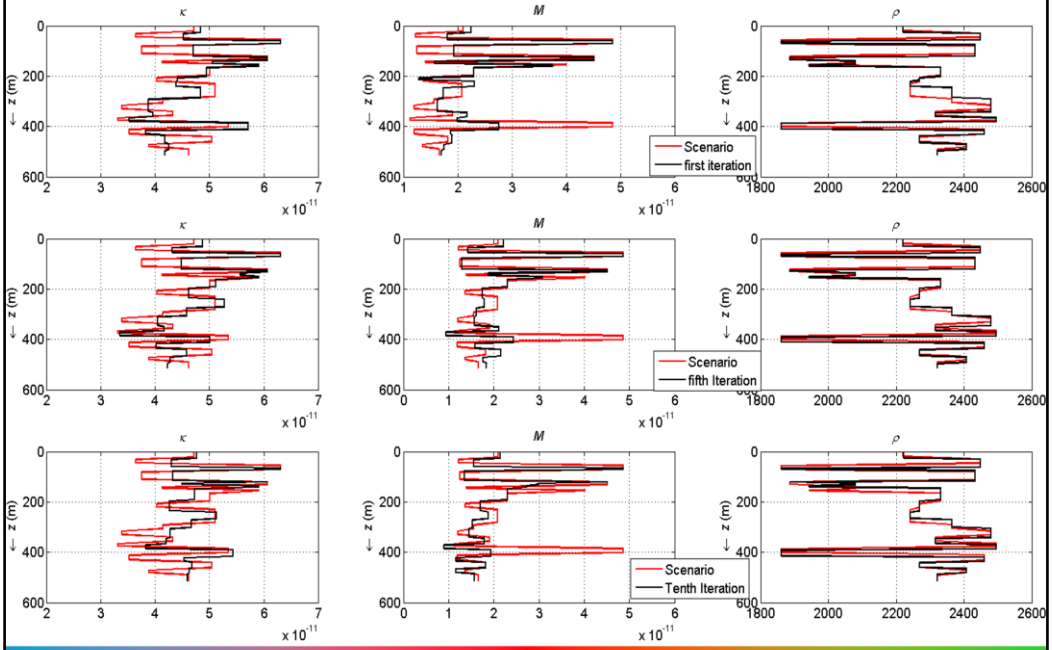
Unconstrained Inversion Result



The Blocking Result



The Blocky Models vs. the Scenario



Conclusions

- Bringing in prior information in the form of a blocky model with means and co-variances for all layers, based on geological knowledge, can bring out features beyond seismic resolution as long as they are consistent with the band-limited inversion result.

- The blocking process improves the static model iteratively using the full-waveform seismic data.

- Different scenarios can be tested and assigned probabilities according to “How well the scenario describes the data”.

Acknowledgement

I would like to thank CGG Jason for providing the software for building the geological model.

Thank you !