Facies Inversion with Plurigaussian Lithotype Rules

Lewis Li [1] Siyao Xu [2] Paul Gelderblom [2]

[1]Department of Energy Resources Engineering, Stanford University, Stanford, CA USA 94305

[2]Shell International Exploration and Production, Houston, TX USA 77082

Overview

Accounting for facies in seismic inversion allow for generating models conditioned to geological concepts, and plays an important role in decision making. In this study, we present an inversion methodology based on Plurigaussian simulations. This is built as an extension to Shell's proprietary probabilistic model-based inversion engine Promise.

Introduction

In conventional modeling workflows, facies are obtained by performing inversion at an acoustic scale, then clustering the inverted properties into facies. We instead incorporate facies modeling into Shell's proprietary probabilistic inversion engine [1] Promise. We invert for two continuous parameters (herin termed *Guide Variables*), and apply a Plurigaussian classification to obtain facies [2]. A Metropolis Iterative Sampler [3] is applied until convergence is achieved.

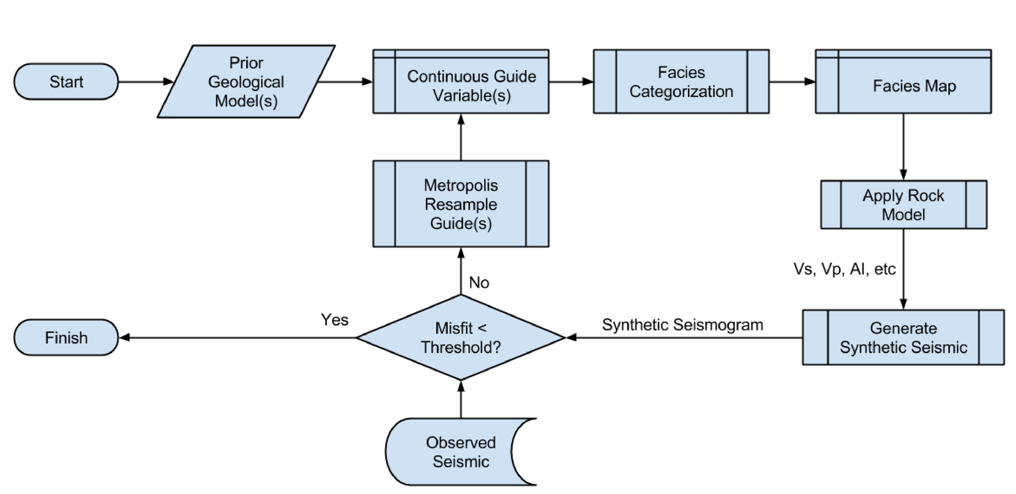

Figure 1: Overall workflow for facies inversion. The inversion process solves for a pair of continuous guide variables that will be classified into facies.

Lithofacies Rule Map

The Lithofacies Rule Map (LRM) is used to convert the guide variables into facies. Obtaining the LRM from a prior geological model is governed using the following rules:

Rule 1: The area of a given facies F_i on the lithotype rule map, will be equal to the proportion of the facies in the inversion result.

Rule 2: On the LRM, the ratio between the contact length between facies F_i and F_j yields the frequency of adjacency between facies in the inverted result.

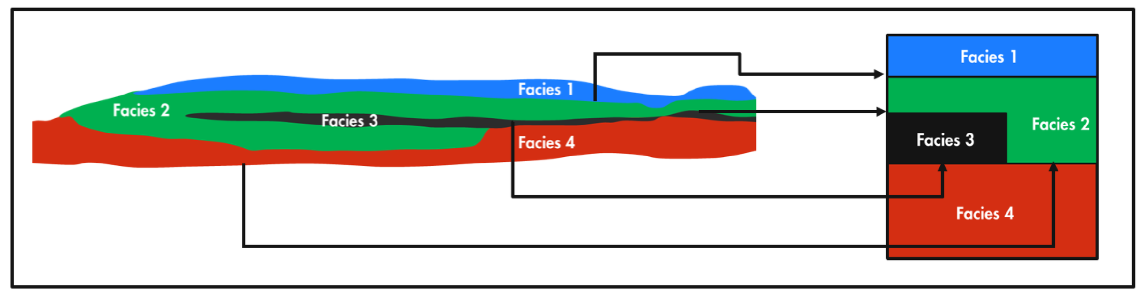

Figure 2: The global proportions of each facies is used to determine the area of the rectangles in the rules map, while the frequency of contacts is used for placement of the areas.

Variogram Modeling

The inversion process requires fitting a variogram for each guide variable from prior facies map (an indicator variogram). It can be shown that for a given LRM, the expected indicator variogram for a facies map, can be related to the two guide variables as:

$$\gamma_{F_i}\left[1_{F_i}(\mathbf{x}), 1_{F_i}(\mathbf{x}+\mathbf{h})\right] = A_i - \iint_{A_i}\iint_{A_i} f(x_1, y_1, x_2, y_2)\, dx_1\, dy_1\, dx_2\, dy_2 \quad (1)$$

Where, A_i is area of facies i in LRM and $f(x_1, y_1, x_2, y_2)$ is a quadvariate Gaussian with zero mean, and covariance matrix defined by:

$$\Sigma = \begin{bmatrix} 1 & \rho & \rho_1(h) & \rho\rho_1(h) \\ \rho & 1 & \rho\rho_2(h) & \rho_2(h) \\ \rho_1(h) & \rho\rho_1(h) & 1 & \rho \\ \rho\rho_1(h) & \rho_2(h) & \rho & 1 \end{bmatrix} \quad (2)$$

We proceed by tuning the two guide variograms until the expected indicator variogram matches that of the prior empirical variogram.

Application: Synthetic Wedge

For the purpose of demonstrating this process, a study was conducted on a synthetic wedge with maximum thickness of 90m and 3 facies (sand, shale, and sand-shale mix). An acoustic scale inversion was performed and shown in Figure 3. The true guide variograms were used for inversion to yield the results in Figure 4.

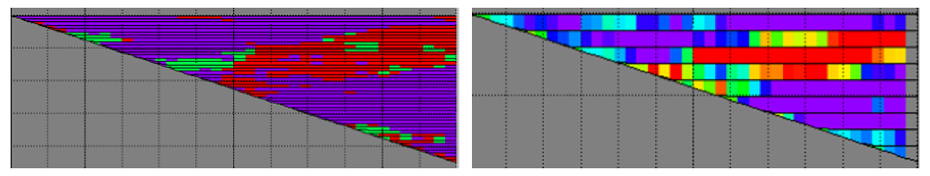

Figure 3: Acoustic scale inversion on synthetic wedge.

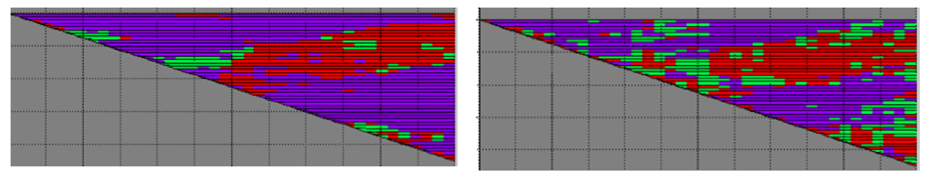

Figure 4: Plurigaussian inversion on synthetic wedge.

Application: Deepwater Reservoir

The new facies inversion algorithm was performed on a Deepwater Offshore Reservoir. The LRM and variograms were derived from a prior facies map obtained through conventional facies modeling workflows [4]. The resulting sand fractions are shown in Figure 6.

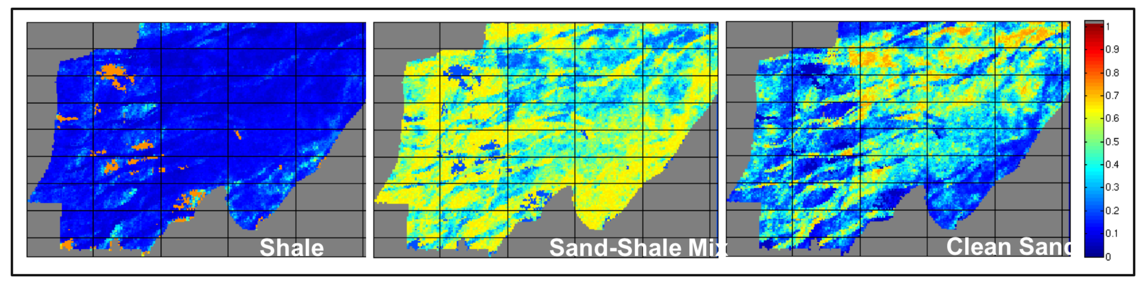

Figure 5: Input facies probability for each facies used for deriving inputs to Plurigaussian inversion.

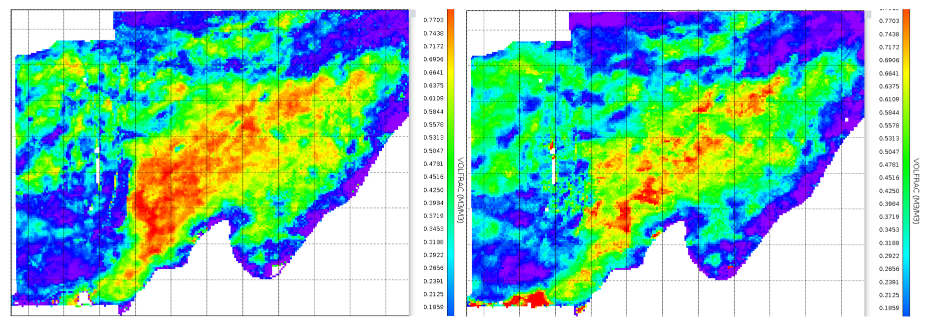

Figure 6: Arithmetic average map of sand fraction over inversion results with cell volume as weight for acoustic (left) and Plurigaussian inversion (right).

Conclusion

We have presented a fine-scale inversion methodology that can resolve facies at a sub-seismic resolution. The workflow requires modeling of a Lithofacies Rules Map that dictates that facies proportions and contacts. A method was also proposed to model two variograms required for inversion, from a single prior facies map. Inversion results on both synthetic and real data shows increased resolution and delineation of specific features that could have large impacts on drilling and other decisions.

References

[1] Jaap Leguijt.
Seismically constrained probabilistic reservoir modeling.
The Leading Edge, 28(12):1478–1484, 2009.

[2] Margaret Armstrong, Alain Galli, Hélène Beucher, Gaelle Loc'h, Didier Renard, Brigitte Doligez, Rémi Eschard, and Francois Geffroy.
Plurigaussian simulations in geosciences.
Springer Science & Business Media, 2011.

[3] Paul Gelderblom, Jaap Leguijt, et al.
Geological constraints in model-based seismic inversion.
In *2010 SEG Annual Meeting*. Society of Exploration Geophysicists, 2010.

[4] Per Avseth, Tapan Mukerji, and Gary Mavko.
Quantitative seismic interpretation: Applying rock physics tools to reduce interpretation risk.
Cambridge university press, 2005.