Quantitative Seismic Interpretation – An Earth Modeling Perspective*

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Search and Discovery Article #41348 (2014)
Posted May 12, 2014

*Adapted from extended abstract prepared in conjunction with oral presentation at CSPG/CSEG/CWLS GeoConvention 2013, (Integration: Geoscience engineering Partnership) Calgary TELUS Convention Centre & ERCB Core Research Centre, Calgary, AB, Canada, 6-12 May 2013, AAPG/CSPG©2014

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Abstract

Earth models are routinely used in the oil and gas industry to integrate multidisciplinary data and to predict the subsurface conditions. While most earth models predict reasonably well at the field scale, they often fail to accurately predict the subsurface conditions at a specific location, especially in stratigraphically complex reservoirs. Several advanced 3D seismic interpretation workflows are available to create more reliable earth models: inversions, seismic stratigraphy and geomorphology amongst others. But these workflows are often used as standalone projects. In addition a common pitfall for interpreters is to go from a qualitative to a quantitative interpretation without accounting for the workflows assumptions and limitations. The purpose of this article is to review the different ways of integrating advanced 3D seismic interpretation results to better constrain an earth model (from pre- and post-stack inversions, to seismic stratigraphy and geomorphology). Various examples will be used to discuss pitfalls and practical solutions for a successful quantitative seismic interpretation. Particular attention will be paid to the use of local geostatistics to integrate 3D seismic data into an earth model.

Introduction

As the industry keeps pushing the limits of exploration and production into marginal and unconventional reservoirs, geoscientists must create more predictive earth models in order to maximize exploration and development successes. A lot of resource plays are data rich, but today a majority of earth models still under utilize the data available. A classic example is the under-utilization of 3D seismic into earth models. Various domestic and international examples of clastic reservoirs will be used to demonstrate what type of information can be extracted from 3D seismic, and how it can be successfully integrated into an earth model. The results: more realistic and more predictive earth models. In other words: the key for geoscientists to have a positive impact on the success of exploration and development programs.

Method

The best way to quantitatively interpret seismic data is to cross-validate it against geological and engineering data. So the first thing needed is to integrate as much data as possible with 3D seismic: a structural and/or stratigraphic interpretation, well data (logs, core, image logs, dip meters, etc.), engineering data (perforation and completion, production history, etc.) and more. The use of geomodeling software is ideal since most commercial versions offer good integration capabilities with the required statistical and geostatistical tools for proper data investigation and modeling.

The depth domain is preferred as it requires fewer efforts to convert seismic and time interpretation to depth than all the other types of data back into the time domain. A good tie between the seismic and the wells is mandatory for a successful data calibration. It is relatively easy to get close to zero meter misties, but up to half meter is still acceptable in some cases.

Post-Stack Inversion

Cross-plotting the seismic P-Impedance against the well P-Impedance is mandatory to validate a post-stack inversion. The well P-Impedance needs to be smoothed to match the seismic frequency. A cross plot over several hundreds of meters must give a very strong correlation, since each stratigraphic unit will have different ranges of impedance values. But it is more important to cross plot the data over the formation of interest - the correlation coefficient between the seismic and well impedance will most likely be weaker than over a thicker interval, but it is often still good enough to be used to constrain an earth model. If the P-Impedance correlates well with porosity, then the seismic P-Impedance can be used as soft constraint in the simulation of porosity using Sequential Gaussian Simulation (SGS) with locally varying mean.

Pre-Stack inversion

When it comes to interpreting a pre-stack inversion, and more especially a lambda-rho vs. mu-rho cross plot, deterministic cut-off lines are often used to classify the seismic inversion volumes into lithofacies and fluids. It is a good initial pass to correlate the seismic elastic properties with lithology and fluid properties, but there is uncertainty in the seismic inversion results, and the lithofacies (and fluids) will most likely overlap in the cross plot.

A probabilistic calibration of each inversion volume (e.g. Lambda Rho and Mhu Rho), followed by a statistical combination of the resulting lithofacies probability distribution functions is a more rigorous approach (Nieto et al., 2013). Once the inversion is properly calibrated to the wells, it can be used as soft data to constrain the earth model. For example, the lithofacies probability volumes (Figure 1) can be used as soft constraint in the simulation of lithofacies using Sequential Indicator Simulation (SIS) with locally varying mean.

Seismic Stratigraphy

The stratigraphic layering in an earth model represents 3D correlation lines and it strongly influences the way the wells are correlated in 3D space. If two identical lithofacies on two nearby wells are located on different stratigraphic layers, they might not be connected in the earth model.

Stratigraphic trends can be interpreted using 3D seismic, but do not always cover the full extent of the area modeled. In the McMurray Formation hundreds of small stratigraphic reflectors of a few hundreds of meters long can be interpreted over just a few square miles. Manually picking these trends is not recommended. A better way is to manually pick seeds in areas of interest and then auto-track the stratigraphic reflectors. But a preferred way is probably to use a fully automated stratigraphic auto-picker, which extracts automatically every single reflector from a stratigraphic interval.

As with every automated process, it is important to check the validity of the stratigraphic reflectors extracted from the seismic. The most convenient way is probably to slice through the entire model with the seismic amplitude in the background, the stratigraphic trends displayed as lines and the wells with facies and stratigraphic markers. Visualizing the stratigraphic trends in 3D can also reveal interesting geomorphologic features. These local trends are then used to build a high resolution stratigraphic model using an implicit modeling workflow (Figure 2).

The advantage of using implicit modeling to model the stratigraphy is that different types of trends can be used: seismic reflectors, 3D seismic attributes (dip and azimuth), dip meter data and stratigraphic well markers. Initial tests have shown that the simulation of lithofacies within such high resolution stratigraphic frameworks produces more realistic lithofacies transition and continuity than in conventional top-down stratigraphic frameworks (Bujor et al., 2012), and improves the predictability of the reservoir models. The high resolution stratigraphic grids can also improve the low frequency model of a constrained inversion (Brouwer et al., 2012).

Seismic Geomorphology Interpretation

Seismic amplitude alone often carries a lot of information. Geomorphologic features have specific signatures. The key for the interpreter is to be able to identify them. A combination of cross sections and stratigraphic slices is the key to recognizing geomorphologic patterns and to extract the associated geomorphologic features (Posamentier, 2005). The high resolution stratigraphic model discussed above increases the chances of finding geomorphologic features. An example of a fluvial channel interpreted from a 3D seismic using the high resolution stratigraphic model is shown in Figure 3.

There are several ways to extract the geomorphologic features identified. The most commonly used approaches are to pick geobodies, trend lines or discontinuities (boundaries). The next challenge is to successfully integrate this interpretation into an earth model. Once again there are several ways to do so. Some people suggest using deterministic geobodies to split the earth model into distinct sub-regions and interpolate or simulate lithofacies and petrophysical properties independently into each sub-region. While this might appear as a legitimate way to proceed, this approach gives a false sense of certainty by ignoring the uncertainty of the geometry of the geobodies interpreted. Furthermore, some geobodies or sub-regions might lack well data to provide enough statistical information to be used in a geostatistical algorithm/workflow.

A more rigorous solution is to use the geomorphologic features to influence the soft data (e.g. facies probability volumes) and the variograms (e.g. variogram maps) that are being used in the interpolation or simulation of lithofacies and petrophysical data. This can be done using local geostatistics.

Local Geostatistics

Standard geostatistical and estimation techniques are constrained by the assumption of stationarity. Properties are interpolated or simulated using a constant set of proportions (facies) or histograms (petrophysical parameters) and a constant set of variogram parameters for the modeled area. Local geostatistics enable the use of local parameters to constrain the interpolation or simulation of lithofacies and petrophysical properties.

The majority of earth models use some soft data in addition to the wells (vertical proportion curves or trends, maps, 3D probability cubes) in an attempt to account for the non-stationarity of the modeled area. But most of the time a single set of variogram models is used even in fluvial channel deposits like the example of Figure 4. The use of locally varying variograms clearly helps differentiating the mud filled abandonment channels from the sandy point bars. Channel deposits are therefore simulated with a greater geological realism.

Conclusions

A lot of valuable information lies in most 3D seismic. Pre- and post-stack inversions, seismic stratigraphic and geomorphologic interpretation, amongst other techniques, are used to extract some of this information. It is then used to constrain earth models using local geostatistics in order to build more predictable and more realistic models.

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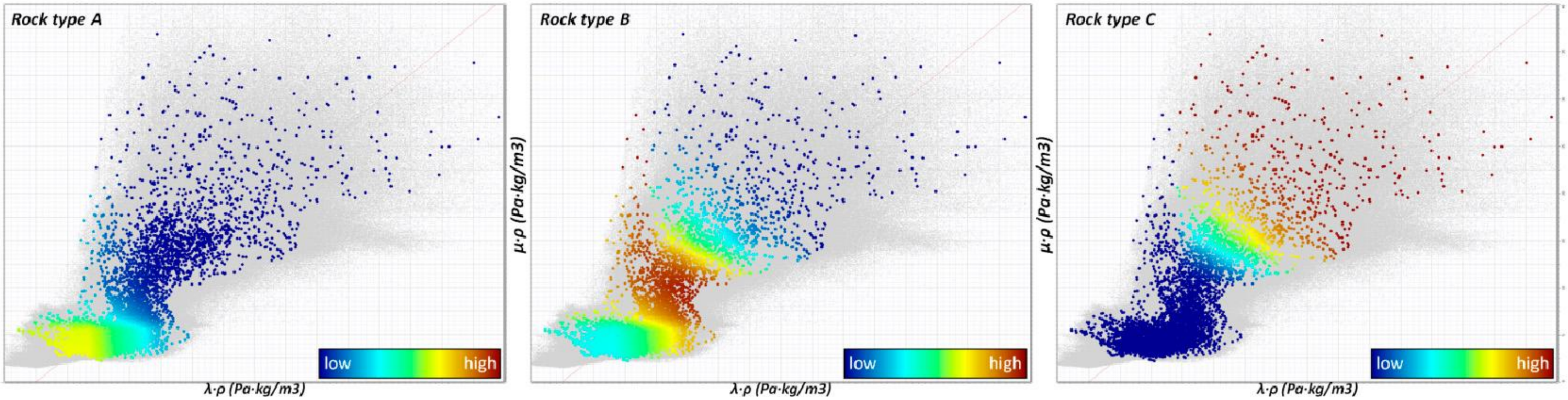

Figure 1. Example of LMR cross plots in the McMurray Formation. The points are colored by three different rock types probability at the well locations (remaining seismic between the wells is shown in grey).

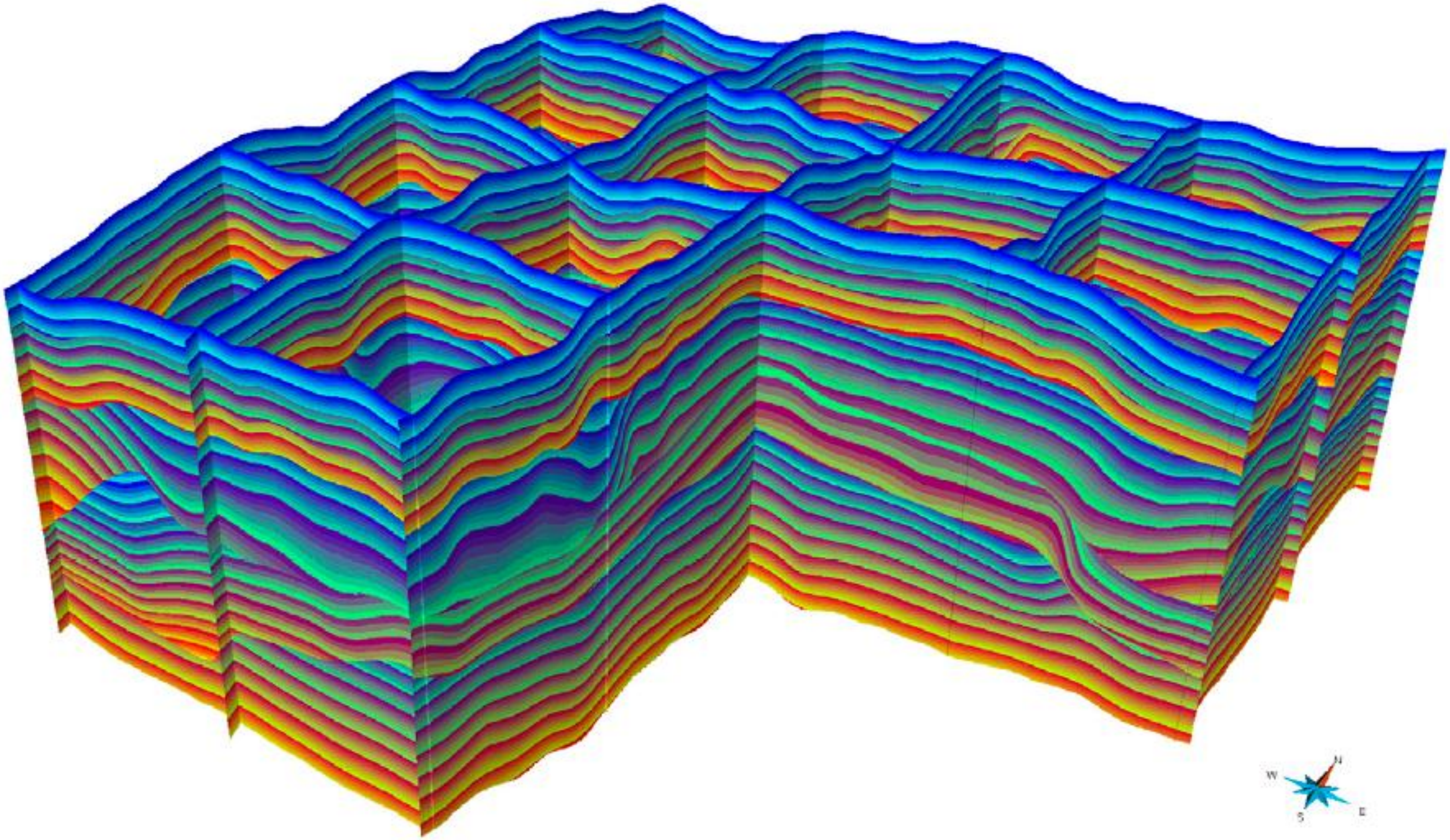

Figure 2. Example of high resolution stratigraphic framework constrained by 3D seismic used to model the McMurray Formation (color represents relative stratigraphic age).

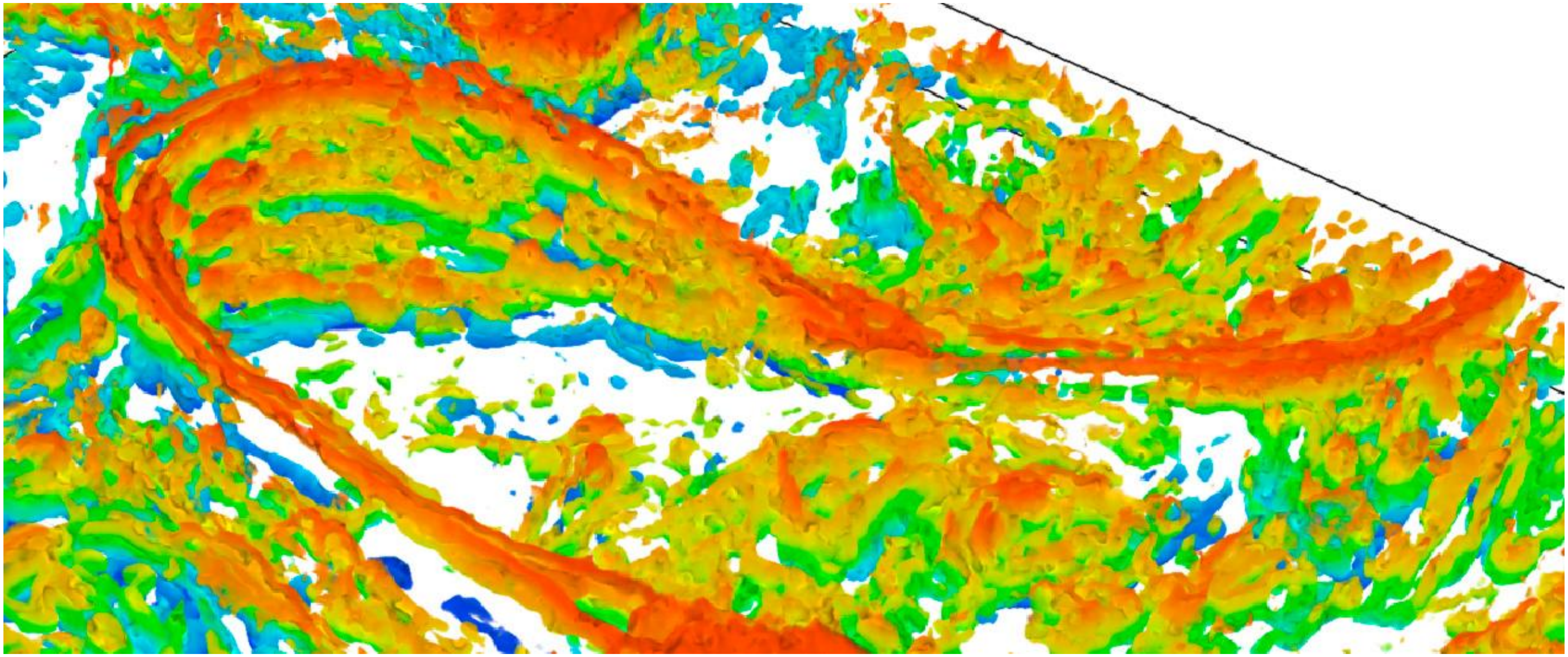

Figure 3. 3D volume rendering of a fluvial channel extracted from 3D seismic in the Mannville Group of the Western Canadian Sedimentary Basin (color represents relative stratigraphic age).

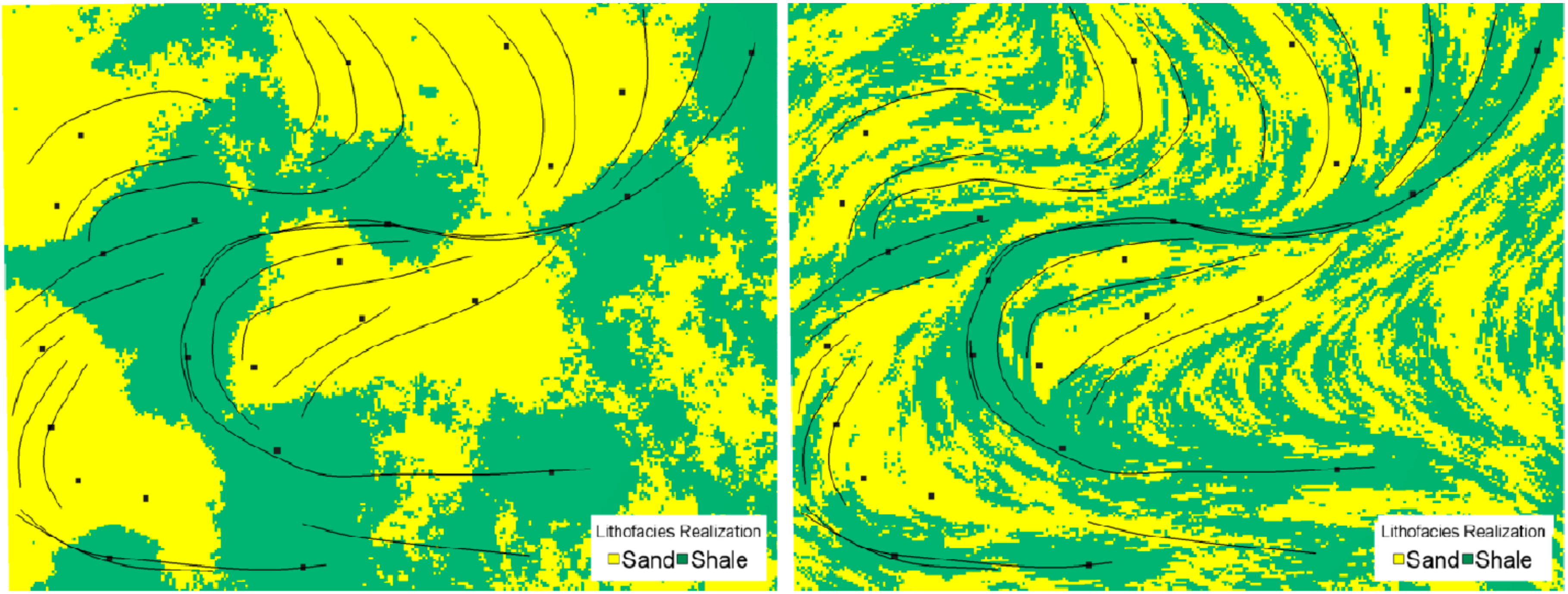

Figure 4. Map of lithofacies simulated from well data (displayed as black squares) with a single variogram model (left) versus a locally varying variogram model (azimuth and ranges) derived from the fluvial channels trends interpreted from seismic geomorphology (black lines).