Understanding the Reservoir Architecture of Lower Fars Formation in North Kuwait through Seismic Reservoir Characterization*

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Abstract

The objective was to decipher the hydrocarbon potential of upper Miocene sandstone reservoirs for extensive field development using the seismic reservoir characterization. The two sandstone layers in the upper Miocene unit showed high complexity because of their lateral facies changes that needed to be investigated. The challenge is to discriminate between reservoir and non-reservoir facies using elastic properties and petrophysical properties. The use of modeled elastic logs was critical to achieve the lithological discrimination needed. Methodology was subdivided into two phases: The first phase was achieved by selecting appropriate wells and the existence of shear logs that cover the zone of interest. After that a series of histograms and cross plots were utilized to reach final conclusions on discrimination for lithology, porosity, and fluid. The second phase was carried out by estimating wavelets and generating pre-stack synthetic seismograms that were used for AVO analysis. Once appropriate low frequency model was built, the combination of P-impedance and S-impedance allowed us to differentiate between layer 1 and layer 2 packages, as well as, for the predictability of shales. A cross plot between P-impedance and porosity showed that as P-Impedance decreases porosity increases for layer 1 and layer 2. However, the inversion results were improved tremendously when the multi-attribute well interpolator model using seismic attributes was used as a background model compared to the low frequency model by using wells only. A better vertical and lateral resolution was achieved and we can see three pronounced events at the reservoir level that are analogous to the prospective zones in the neighboring areas. The salient point of this methodology is the use of multi attributes well interpolator as background low frequency model (LFM) that honour the trend observed in the seismic data as well as the well data. Inverted absolute impedances are in agreement with well impedances. Forward modelling validated the seismic interpretation and it was easier to interpret on the band-pass impedance volume than the actual seismic due to more continuity of the events and less noise content. Upper sandstone layer (F1A) shows promising and encouraging results based on our study and the porosity and net pay estimated showed that the areas with thicknesses greater than 12 ft. are highly prospective.

Selected References

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شركة نفط الكويت
إحدى شركات مؤسسة البترول الكويتية
A Subsidiary of Kuwait Petroleum Corporation

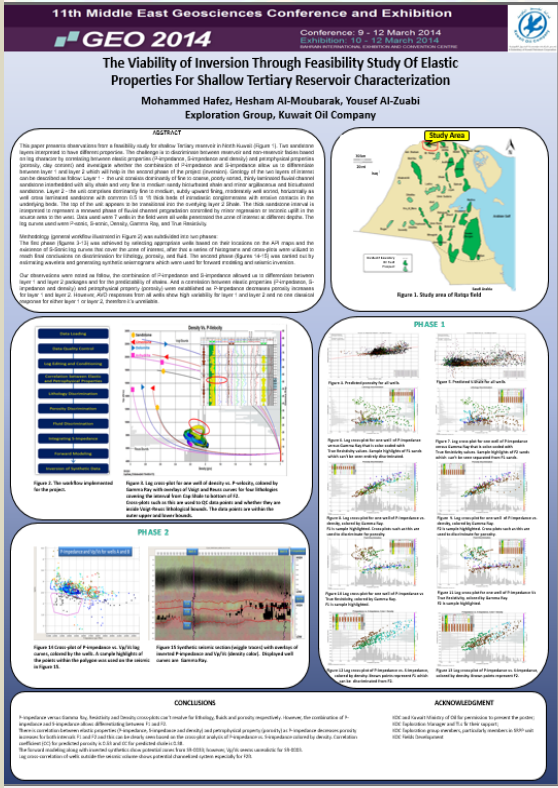
LOOKING BACKWARD ... WHAT WE LEARNED

In northern Kuwait, the Lower Fars Formation is a long established prolific reservoir of heavy oil. The formation is under development in Ratqa field. Heavy oil potential within it is also seen in Raudhatain, Sabiriyah, Bahrah and Mutriba areas.

Two sandstone layers are interpreted to have different properties as shallow Tertiary reservoirs in North Kuwait. The challenge is to discriminate between reservoir and non-reservoir facies based on log character by correlating between elastic properties (P-impedance, S-impedance and density) and petrophysical properties (porosity, clay content) and investigating whether the combination of P-impedance and S-impedance allow us to differentiate between layer 1 and layer 2, an important element in the second phase of the project (inversion).

The thick sandstone interval is interpreted to represent a renewed phase of fluvial channel progradation controlled by minor regression or tectonic uplift in the source area to the west.

Data used were 5 wells in the field were all wells penetrated the zone of interest at different depths. The log curves used were P-sonic, S-sonic, Density, Gamma Ray, and True Resistivity.



LOOKING BACKWA

Geology of the **two layers** of interest can be described as follow:

Layer 1 - the unit consists dominantly of fine to coarse, poorly sorted, thinly laminated fluvial channel sandstone interbedded with silty shale and very fine to medium sandy bioturbated shale and minor argillaceous and bioturbated sandstone.

Layer 2 - the unit comprises dominantly fine to medium, subtly upward fining, moderately well sorted, horizontally as well cross laminated sandstone with common 0.5 to 1ft thick beds of intraclastic **conglomerates with erosive contacts** in the underlying beds. The top of the unit appears to be transitional into the overlying layer 2 Shale.

Core Photograph showing characteristic features of Lower Fars Formation

Conglomerate overlies the cross-bedded sandstone with sharp erosive base

LOOKING BACKWARD … WHAT WE LEARNED

Methodology was subdivided into two phases:

The first phase was achieved by selecting appropriate wells based on their locations on the API maps and the existence of S-Sonic log curves that cover the zone of interest, after that a series of histograms and crossplots were utilized to reach final conclusions on discrimination for lithology, porosity, and fluid. The second phase was carried out by estimating wavelets and generating pre-stack synthetic seismograms which were used for AVO analysis.

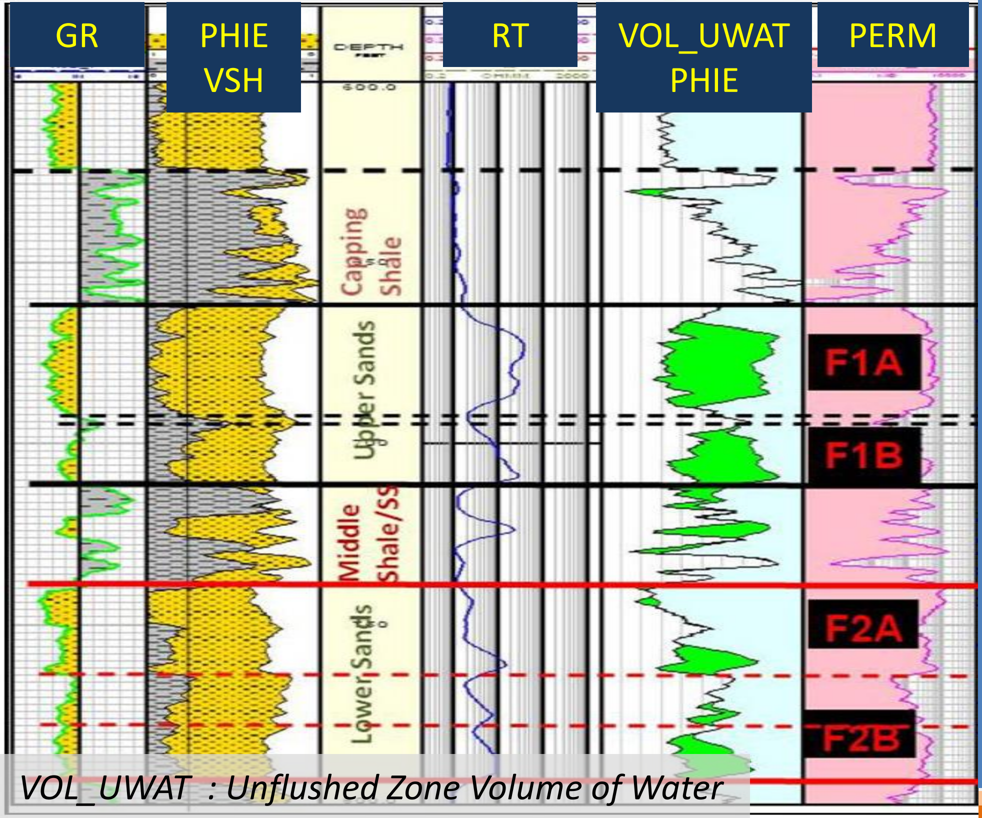
LOOKING BACKWARD … WHAT WE LEARNED

Our observations were noted as follow, the combination of P-impedance and S-impedance allowed us to differentiate between layer 1 and layer 2 packages and for the predictability of shales. And a correlation between elastic properties (P-impedance, S-impedance and density) and petrophysical property (porosity) were established as P-Impedance decreases porosity increases for layer 1 and layer 2. However, AVO responses from all wells show high variability for layer 1 and layer 2 and no one classical response for either layer 1 or layer 2, therefore it’s unreliable.

OBJECTIVES

- To investigate the shale barriers within the layers
- To better classify the facies
- To delineate the channel through seismic facies classification

Type Log of Lower Fars

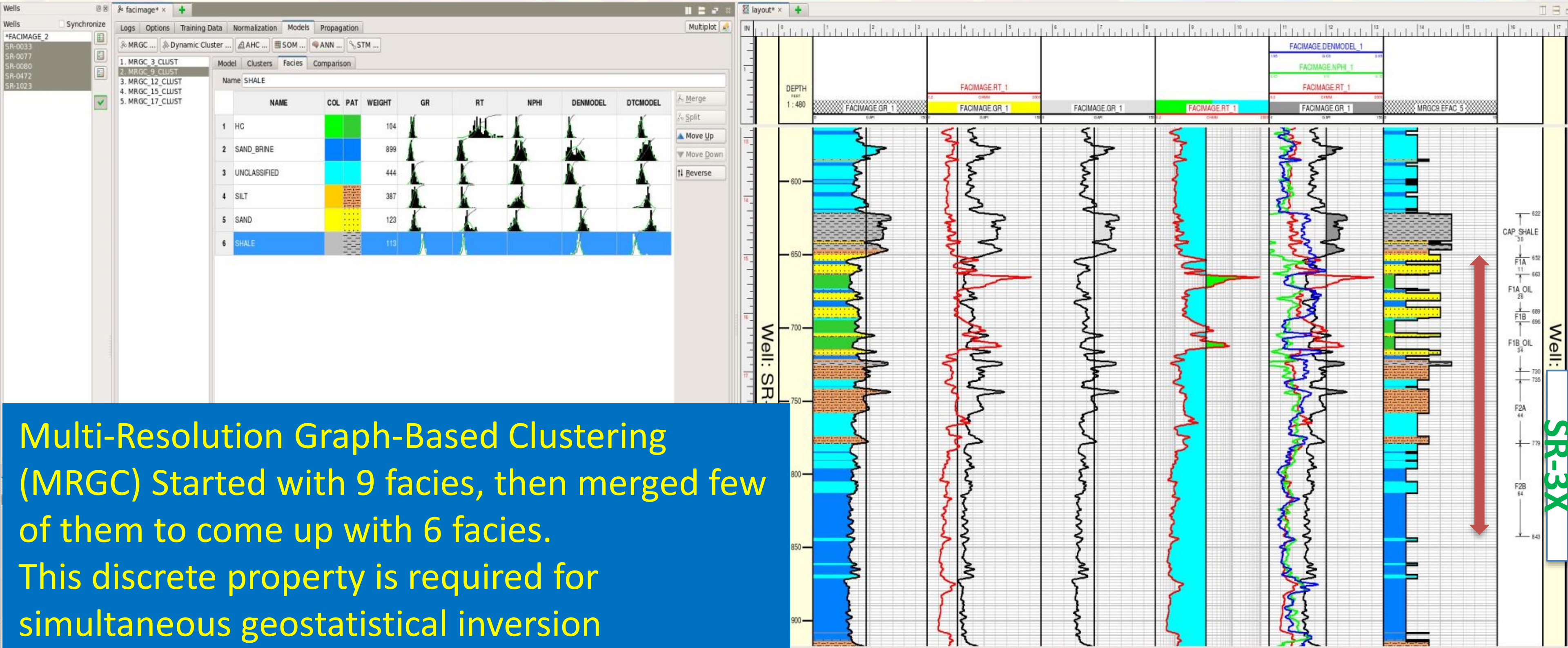


VOL_UWAT : Unflushed Zone Volume of Water

The pay interval of the formation is divisible into four units. Two major reservoir units **F1** and **F2** refer to first and second Lower Fars reservoir sands respectively. The upper reservoir F1 occurs at shallow depths ranging between 400ft and 800 ft.

It is overlain by Cap Shale and is divisible into sands F1A and F1B separated by thin shale. The lower reservoir F2 is capped by Middle Shale and is divisible into sands F2A and F2B separated by thin shale. The Cap Shale overlying the reservoir F1 appears to have acted as the regional cap for the reservoirs as no commercial hydrocarbons are reported above it in Kuwait.

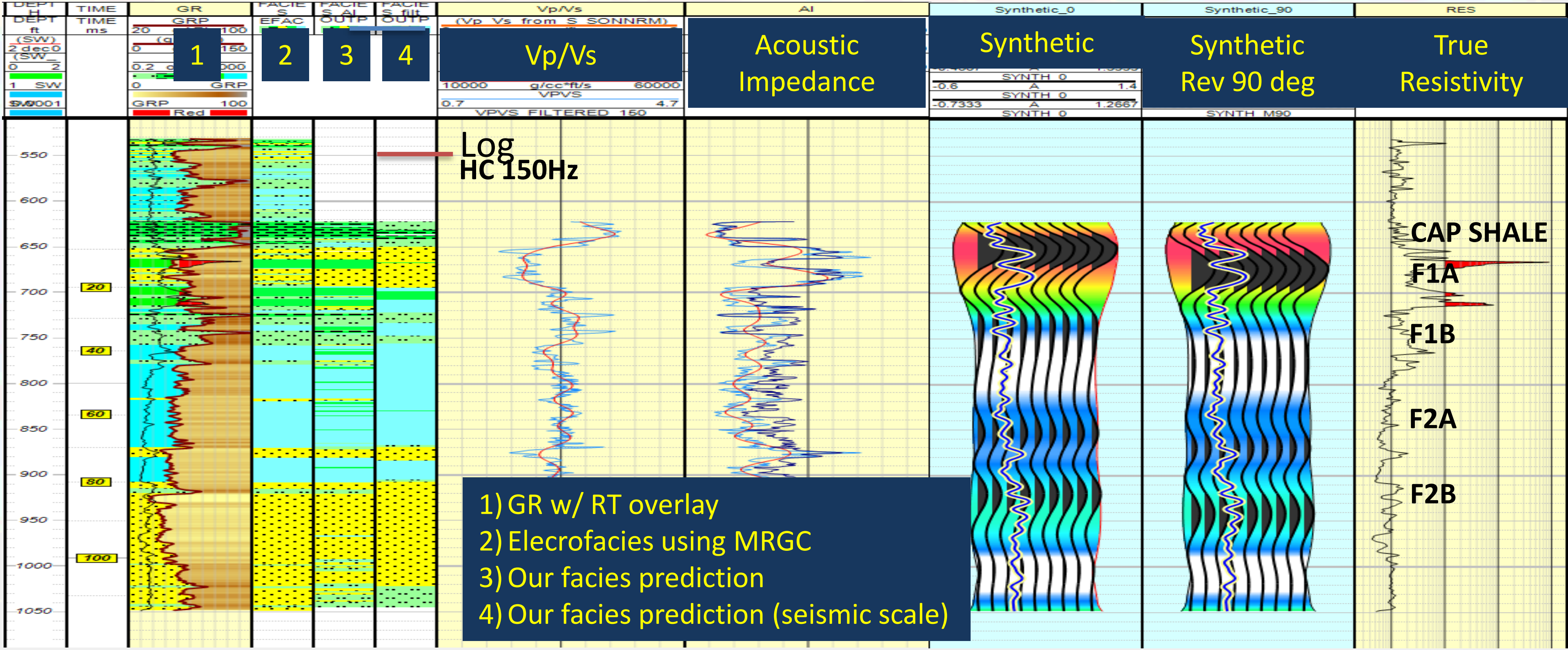
Facies Classification using Neural Network



Multi-Resolution Graph-Based Clustering (MRGC) Started with 9 facies, then merged few of them to come up with 6 facies.

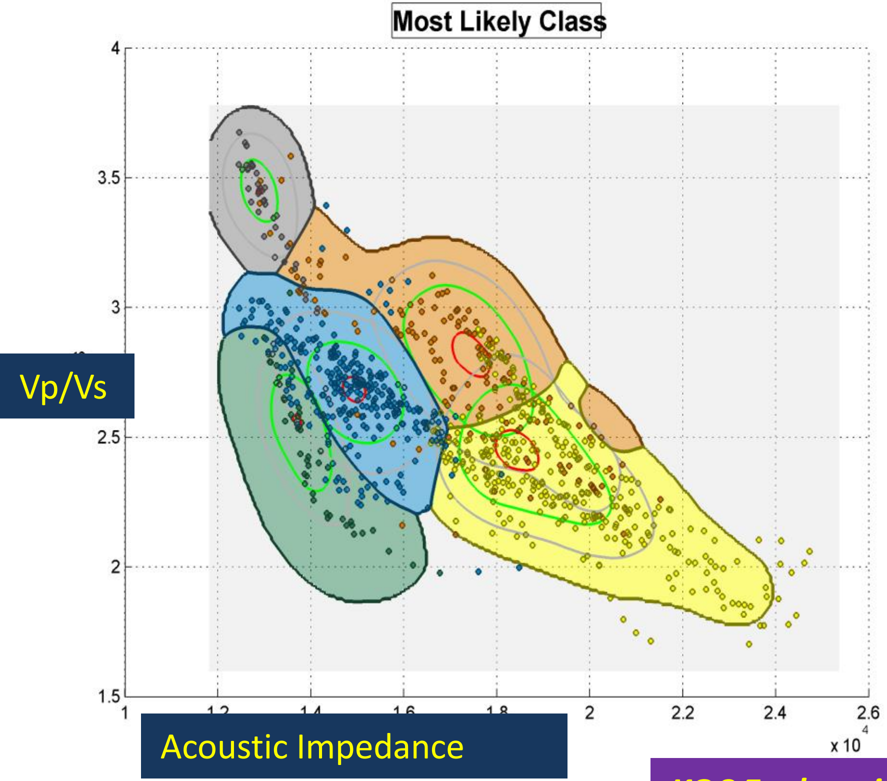
This discrete property is required for simultaneous geostatistical inversion

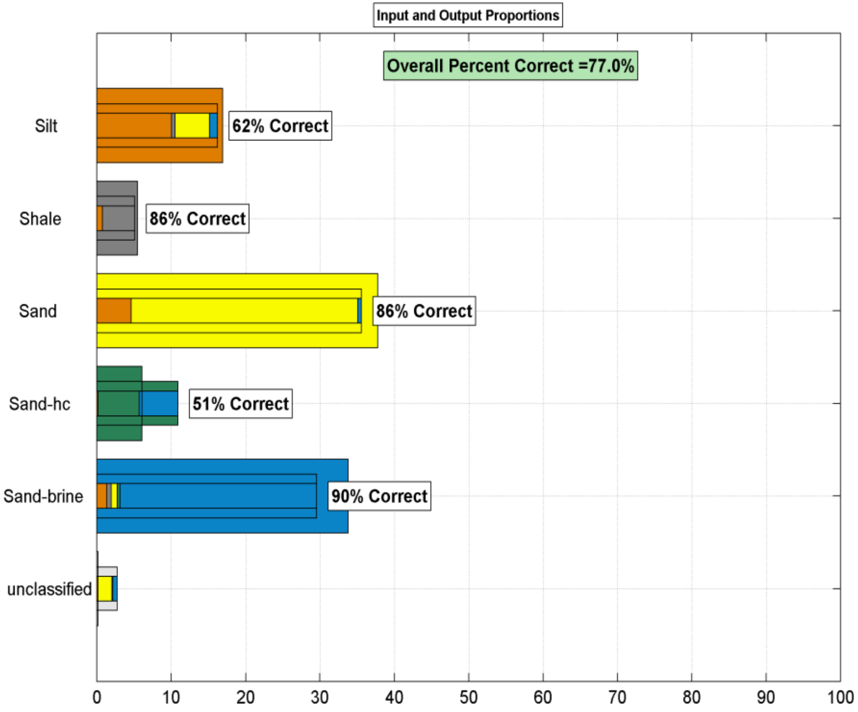
KOC Facies Classification – How Is Our Prediction?



Courtesy of K. Edwards, KOC

Our Facies Classification (Bayesian Approach)

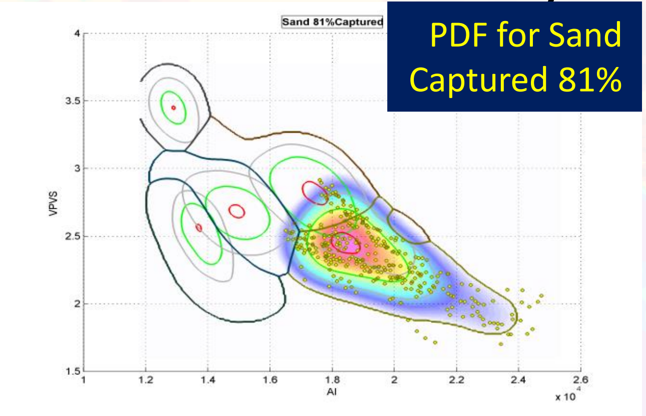


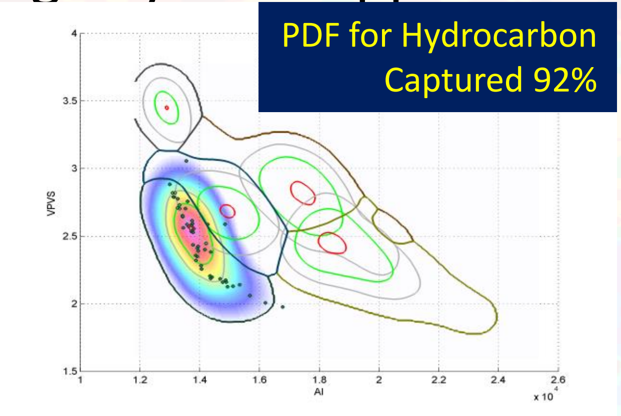


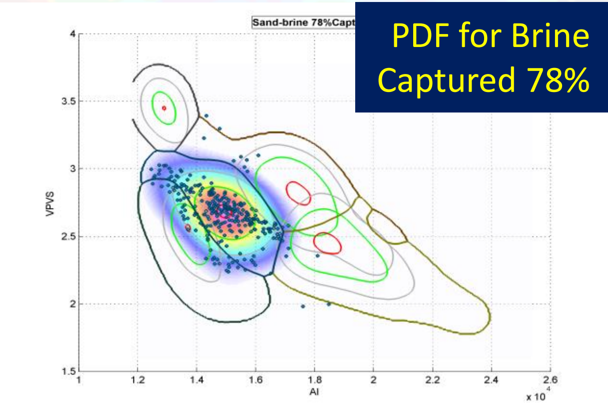
Courtesy of K. Edwards, KOC

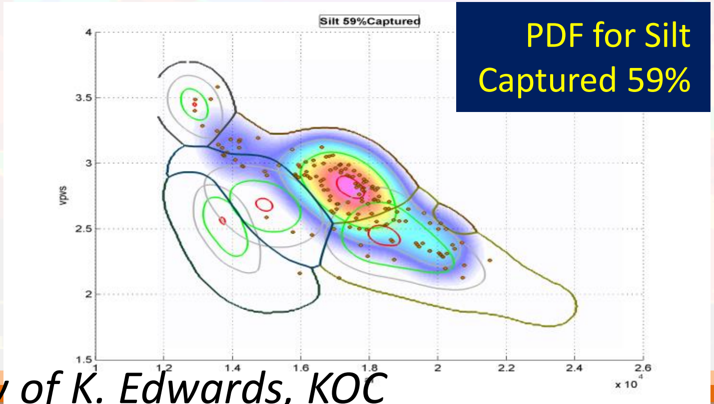
KOC Exploration and R&T Groups developed software

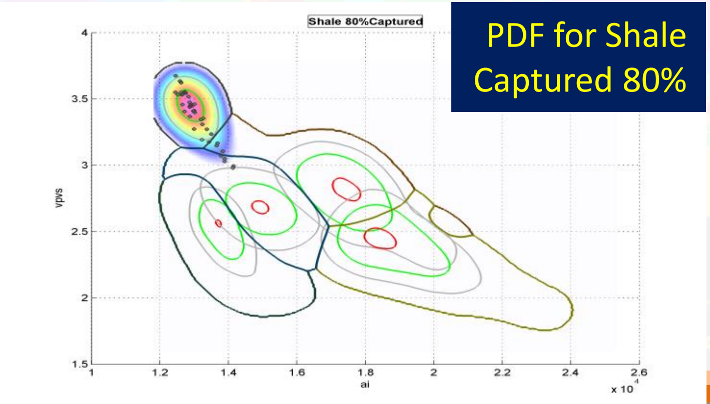
Facies Probability Using Bayesian Approach







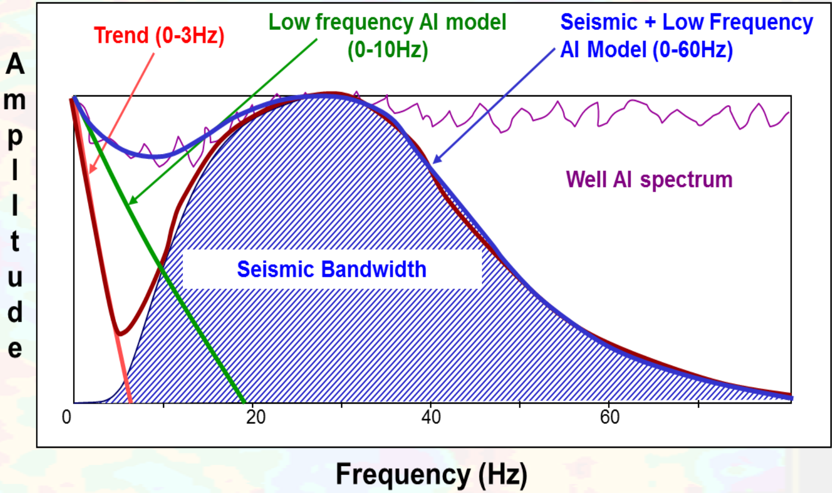




Courtesy of K. Edwards, KOC

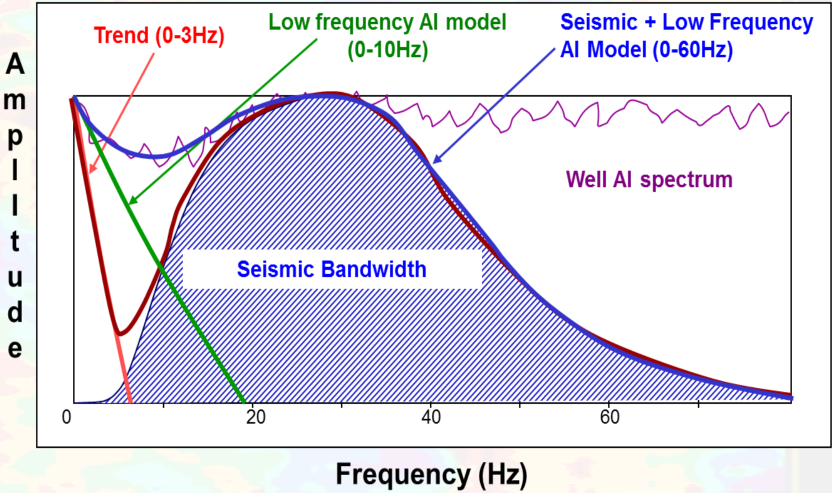
Deterministic Seismic Inversion

- Deterministic inversion is performed in the time domain using different sources of information in the frequency domain:
  - Band limited part comes from seismic
  - Low frequency part comes from a model
- Seismic data has a limited frequency band (in our case 10-90Hz), so well data can fill the low frequency gap (e.g. 0-10Hz) with property trends to give full bandwidth inverted properties (e.g. 0-90Hz)

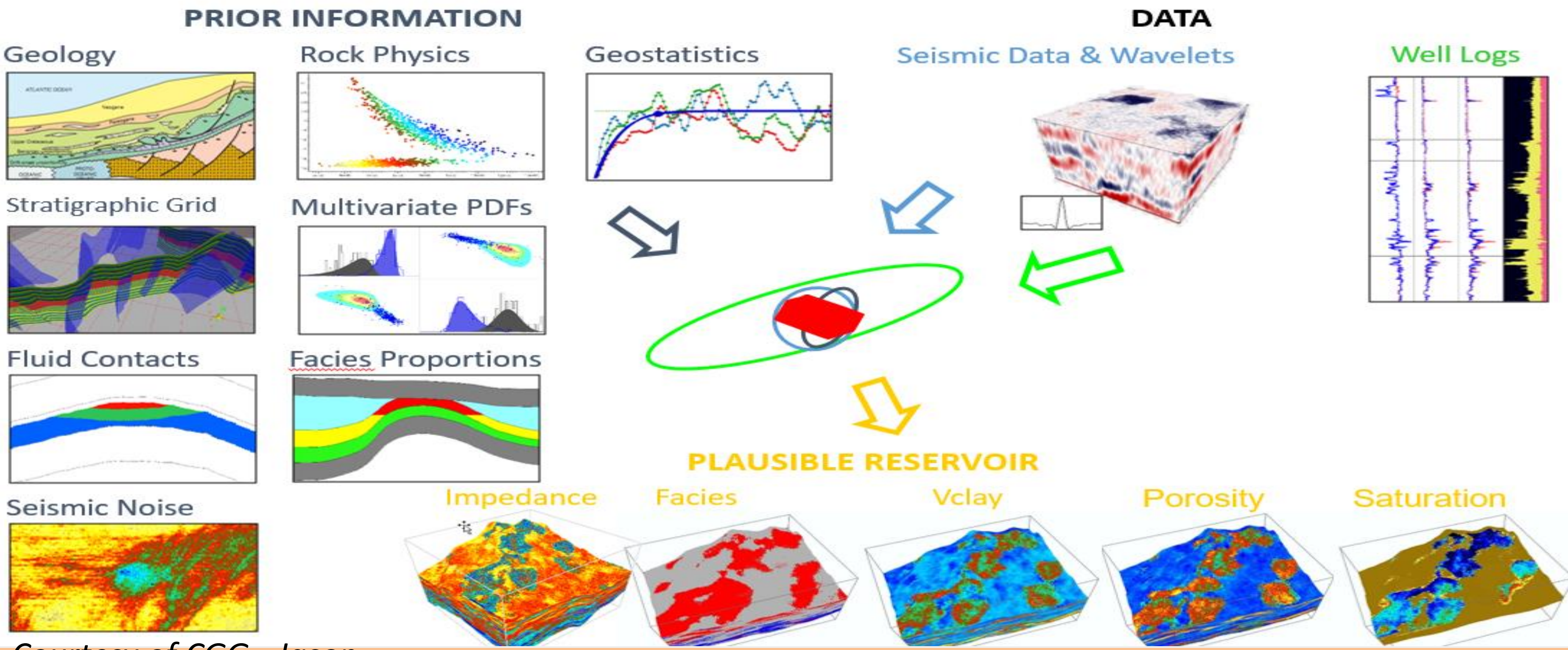


Geostatistical Seismic Inversion

- Geostatistical inversion aims to extend the spectrum of inverted properties to higher frequencies
- Using geostatistics (i.e. property PDFs and variograms) allows to generate multiple high frequency results (above the seismic bandwidth), which are merged with deterministic inversion results
- We used simultaneous geostatistical inversion to jointly invert properties and lithologies at all frequencies



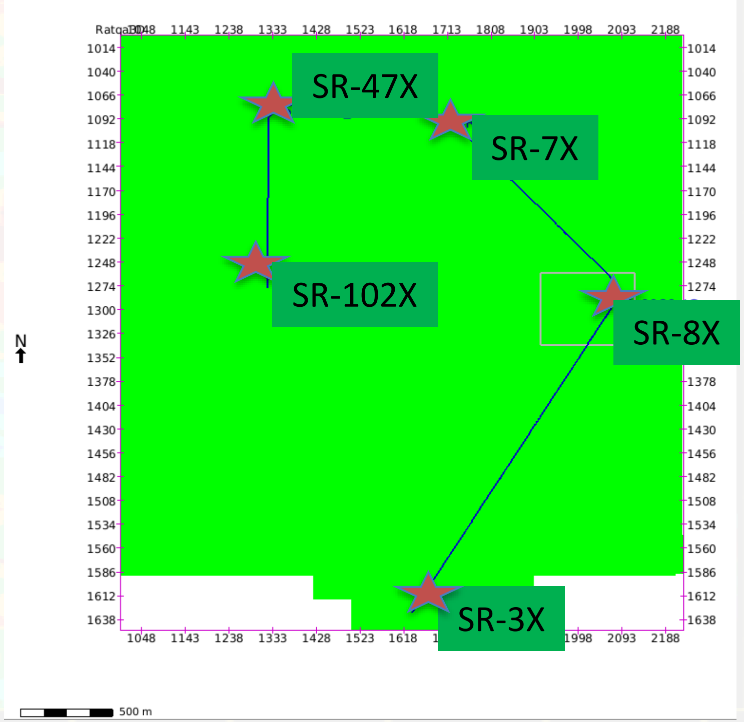
Geostatistical inversion overview



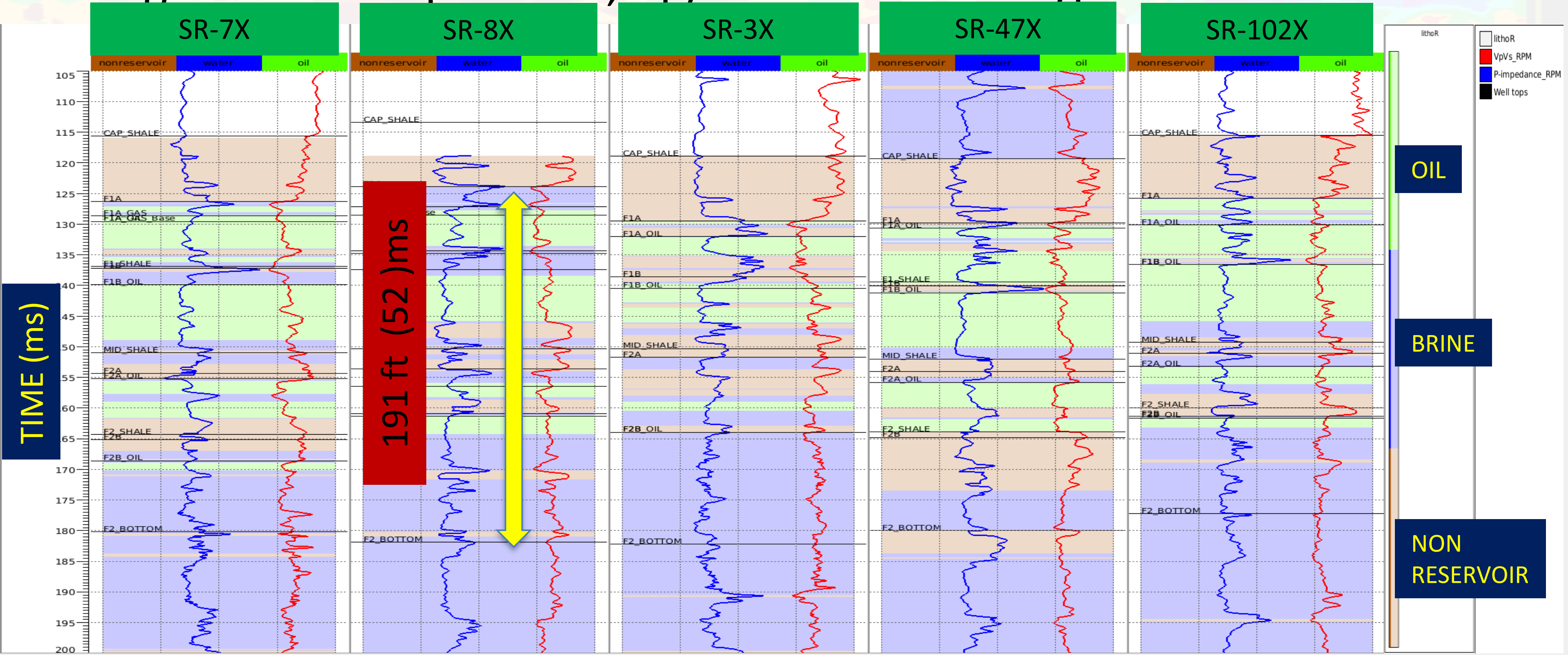
Courtesy of CGG - Jason

Input data

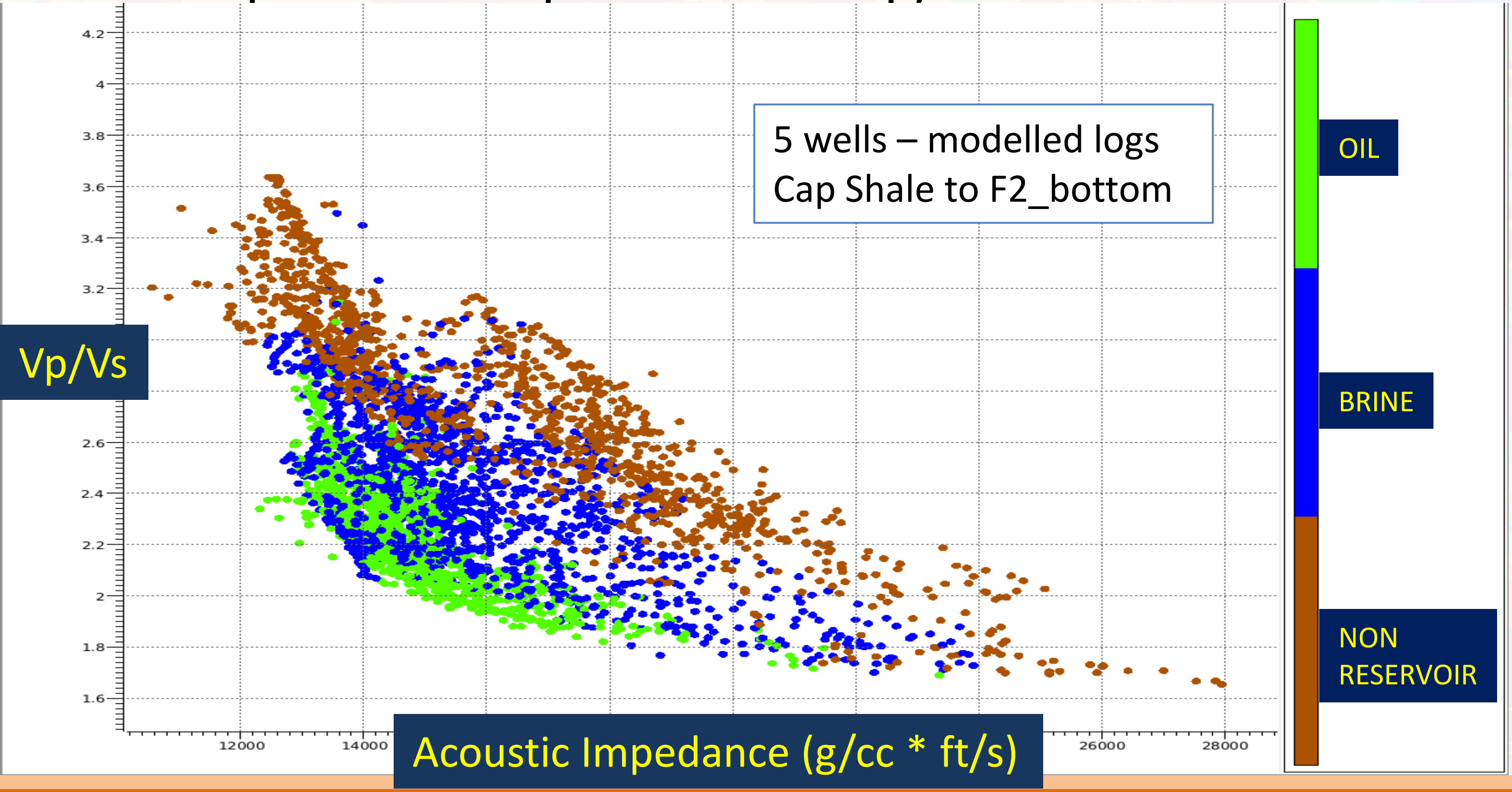
- 5 Seismic Angle Stacks (12-19°, 20-27°, 28-35°,
- 36-43°, 44-51°)
  - Seismic Grid: 5 x 2.5 m
  - Sample Rate: 2ms
- 5 Wells (SR-7x, SR-8x, SR-3x, SR-47x, SR-102x)
  - Modeled P-sonic, S-sonic and Density (from Rock Physics Modeling)
  - Lithotype log (Oil, Water & Non-Reservoir)
- 5 Horizons (F1A, F1B, F2A, F2B, F2B_bottom)
- Wavelets from Deterministic Inversion



Log Data – P-impedance, Vp/Vs ratio & Lithotype



Crossplots – P-impedance vs. Vp/Vs ratio



Cutoffs:

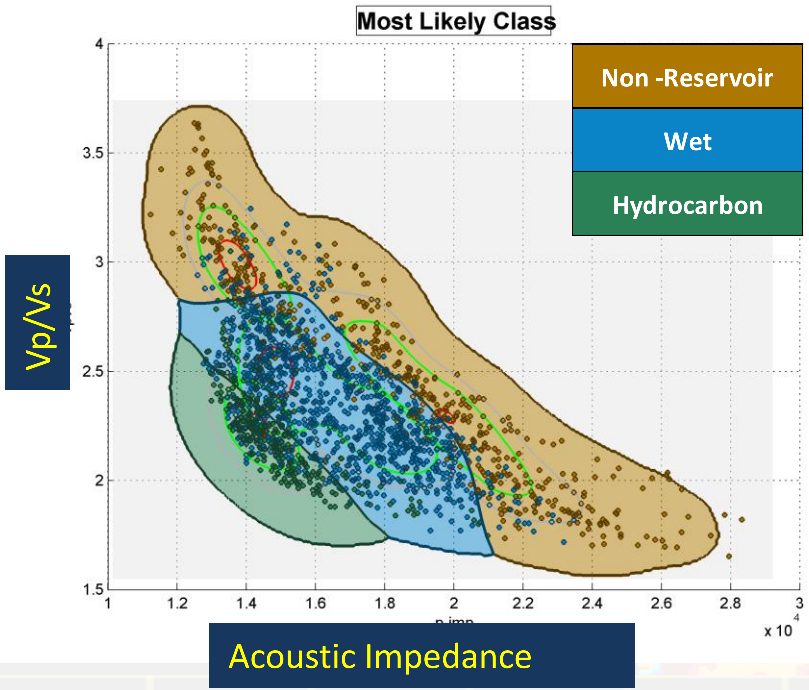
OIL
PHIE>0.20
SW<0.6

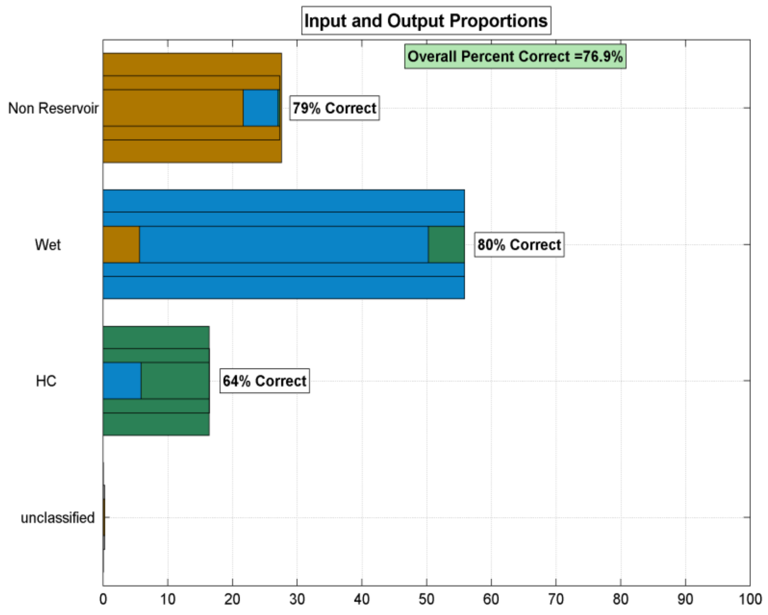
WATER
PHIE>0.20
SW>0.6

NON-RESERVOIR
EVERYTHING ELSE

Rock Typing From Neural Network was fine-tuned

Discrete Bayesian Facies Classification in 2D Elastic Domain Using Modeled Logs

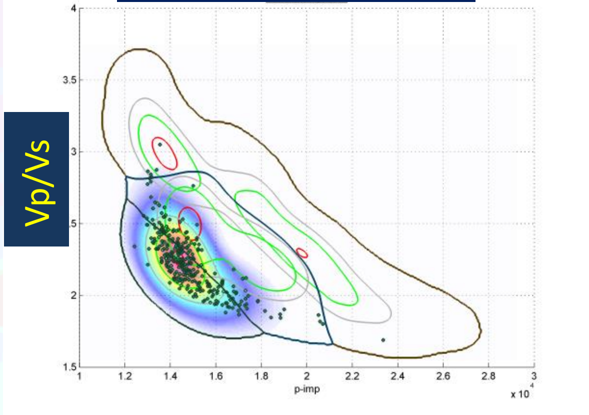




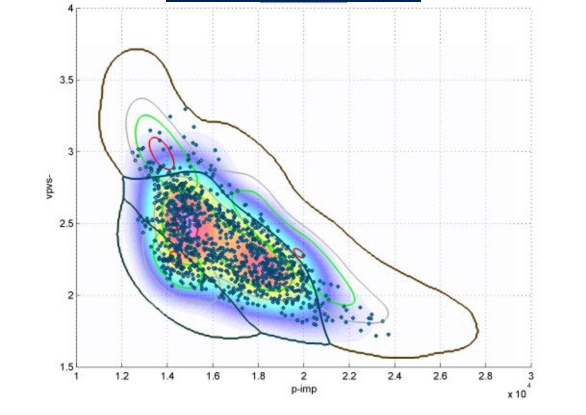
Courtesy of K. Edwards, KOC

Facies Probability of Assignment Using Bayesian Approach

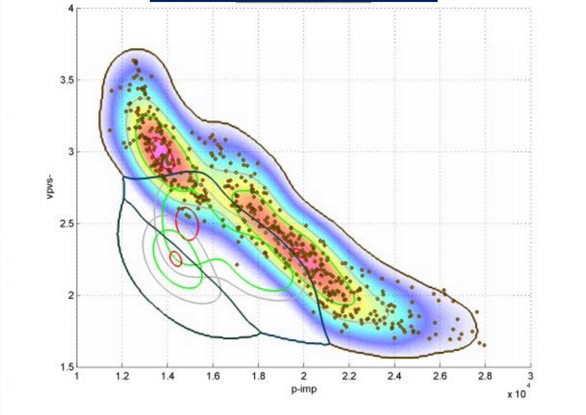
PDF for Hydrocarbon
Captured 64%



PDF for Wet
Captured 80%



PDF for Non-Res
Captured 79%



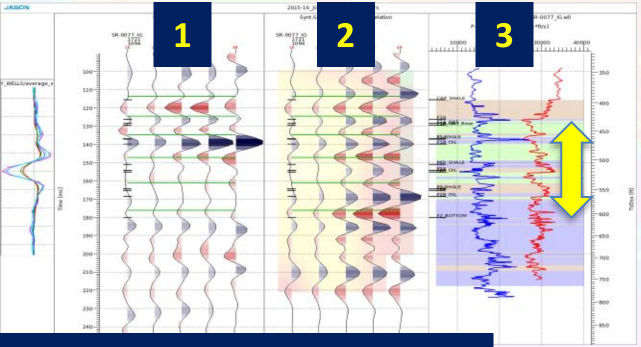
Vp/Vs

Acoustic Impedance

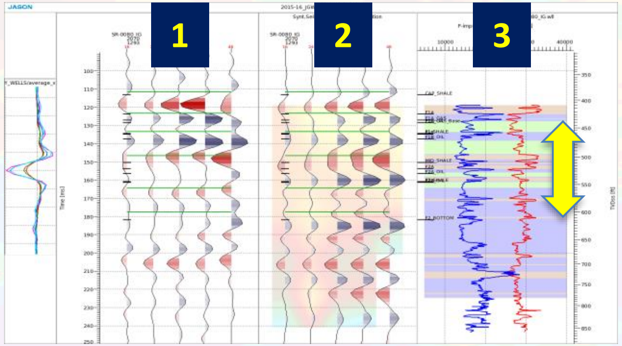
Courtesy of K. Edwards, KOC

Seismic to Well Ties – How Accurate Can My Well Tie Be?

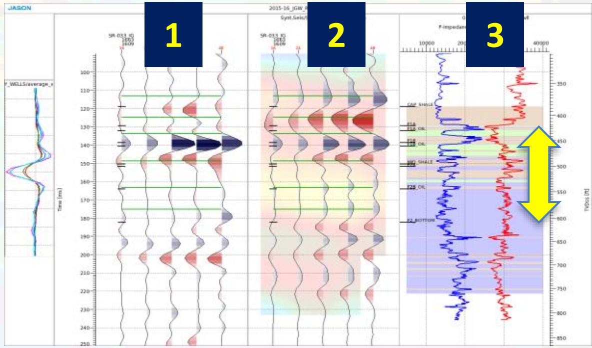
Well Tie – SR-7x



Well Tie – SR-8x



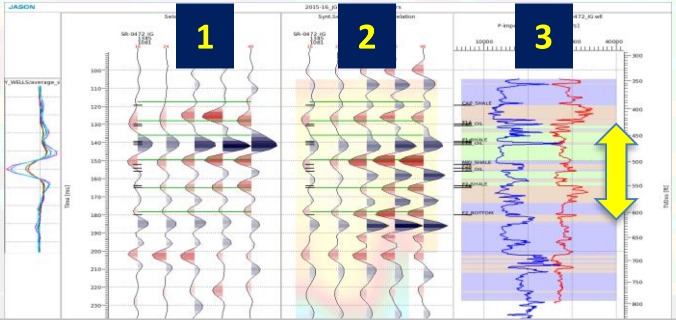
Well Tie – SR-3x



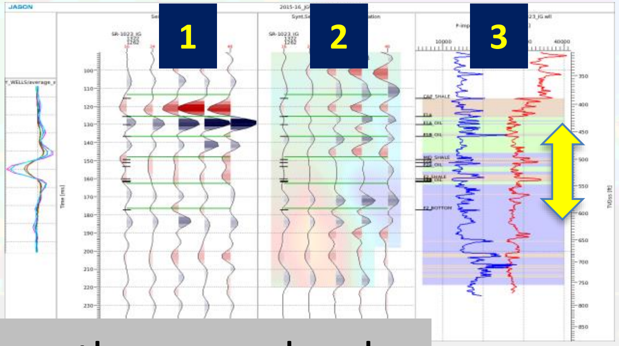
1) Seismic Gather
2) Synthetic Gather
3) P-Impedance (Blue), Vp/Vs (Red) with Lithology in Background

↕ Zone of Interest

Well Tie – SR-04x



Well Tie – SR-10x



Well log synthetic seismograms and seismic data match one another very closely.

Simultaneous Geostatistical Inversion Workflow 1 – setup

- Define stratigraphic grid – layers/sampling
- Define property PDFs & variograms for all pad layers
- Define lithology proportions & variograms for all reservoir layers
- Define property PDFs & variograms for each lithology for all reservoir layers
- Test parameters using simulation mode (i.e. no inversion)
- Test parameters using unconstrained inversion mode (blind wells)
- Test parameters using constrained inversion mode (constraint wells)
- Run multiple realizations
- Analyze QC realizations
- Co-simulation etc.

Parameters for Simultaneous Geostatistical Inversion

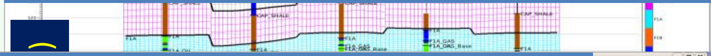
- Stratigraphic grid – 4 reservoir layers (F1A,
- Average micro-layer thickness – 0.5ms
- vertical variograms (for lithotypes & proper
- Horizontal variograms for (lithotypes & pro

Pad layers
- continuous property PDFs & variograms

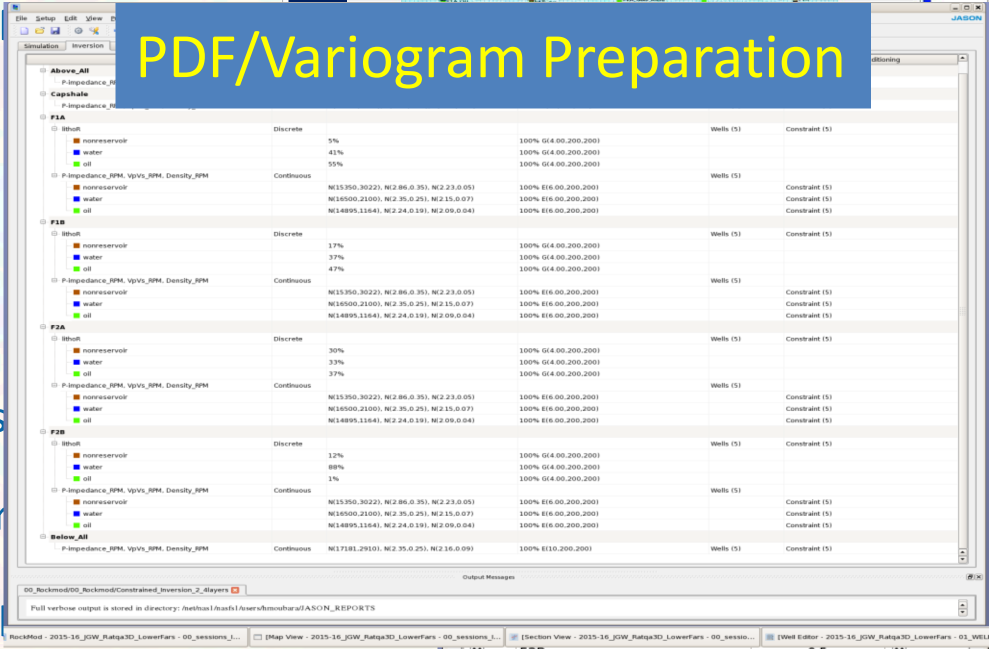
Reservoir layers
- Discrete property proportions & variograms
- Continuous property PDFs & variograms

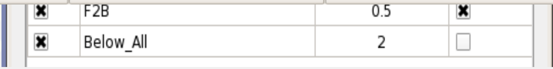
Well conditioning
- Blind or constraint

Stratigraphic Grid for Solid Model with Lithology Overlay

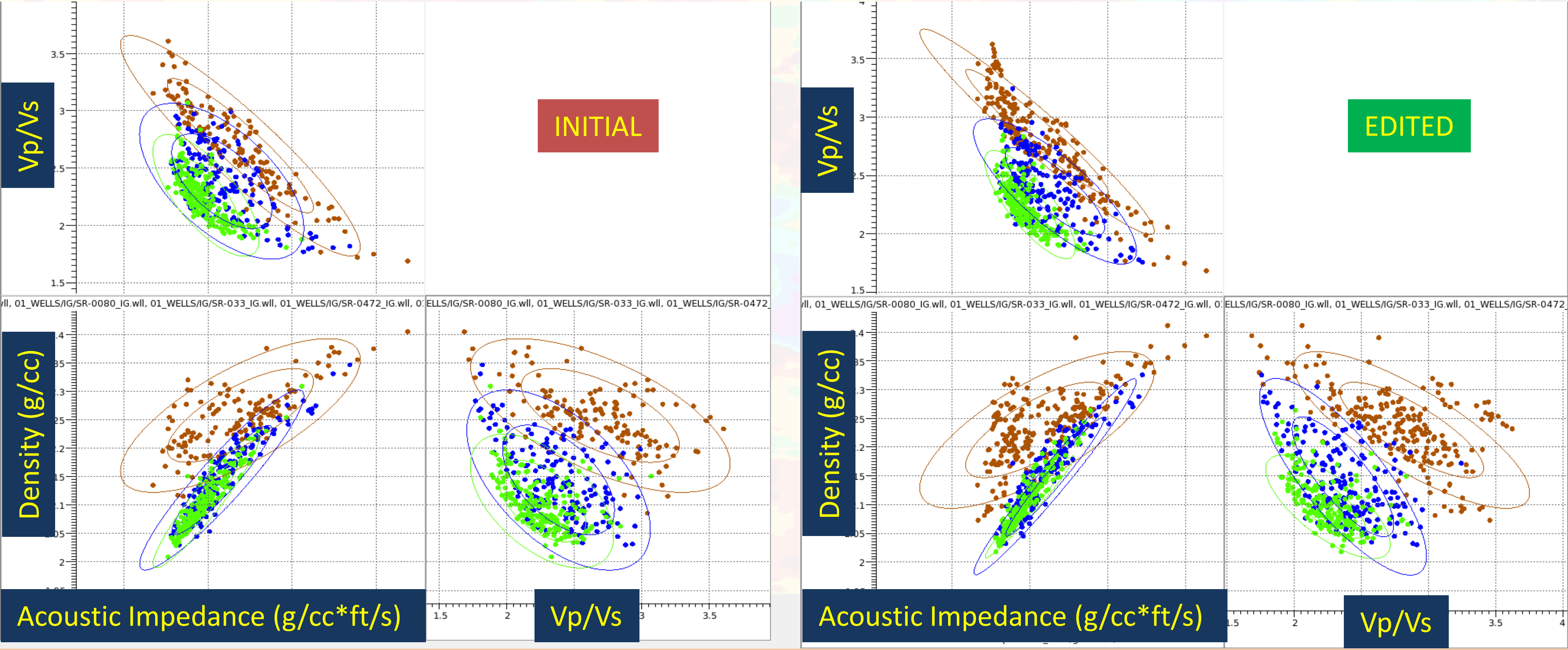


PDF/Variogram Preparation





Elastic property 3-2D PDFs – Initial vs Edited



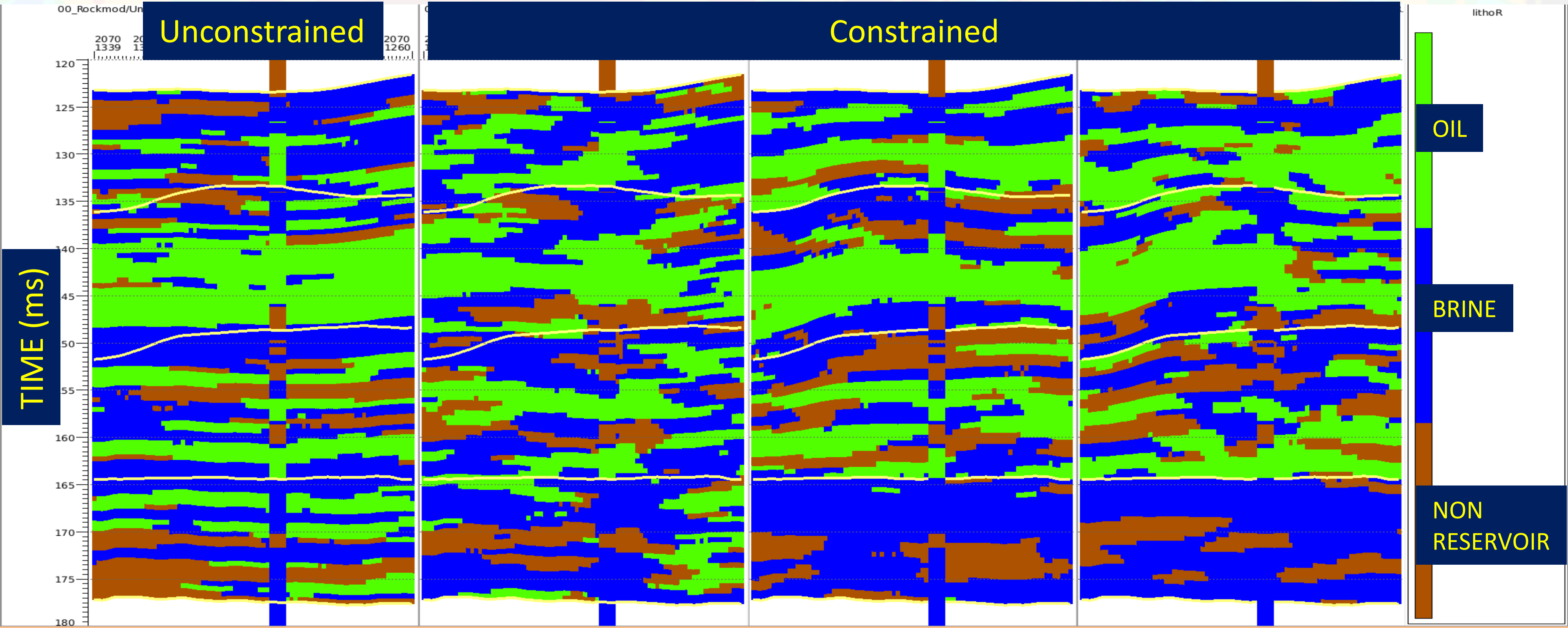
Simultaneous Geostatistical Inversion Workflow 2

- Define stratigraphic grid – layers/sampling
- Define property PDFs & variograms for all pad layers
- Define lithology proportions & variograms for all reservoir layers
- Define property PDFs & variograms for each lithology for all reservoir layers
- Test parameters using simulation mode (i.e. no inversion)
- Test parameters using unconstrained inversion mode (blind wells)
- Test parameters using constrained inversion mode (constraint wells)
- Run multiple realizations
- Analyze QC realizations
- Co-simulation/ranking etc.

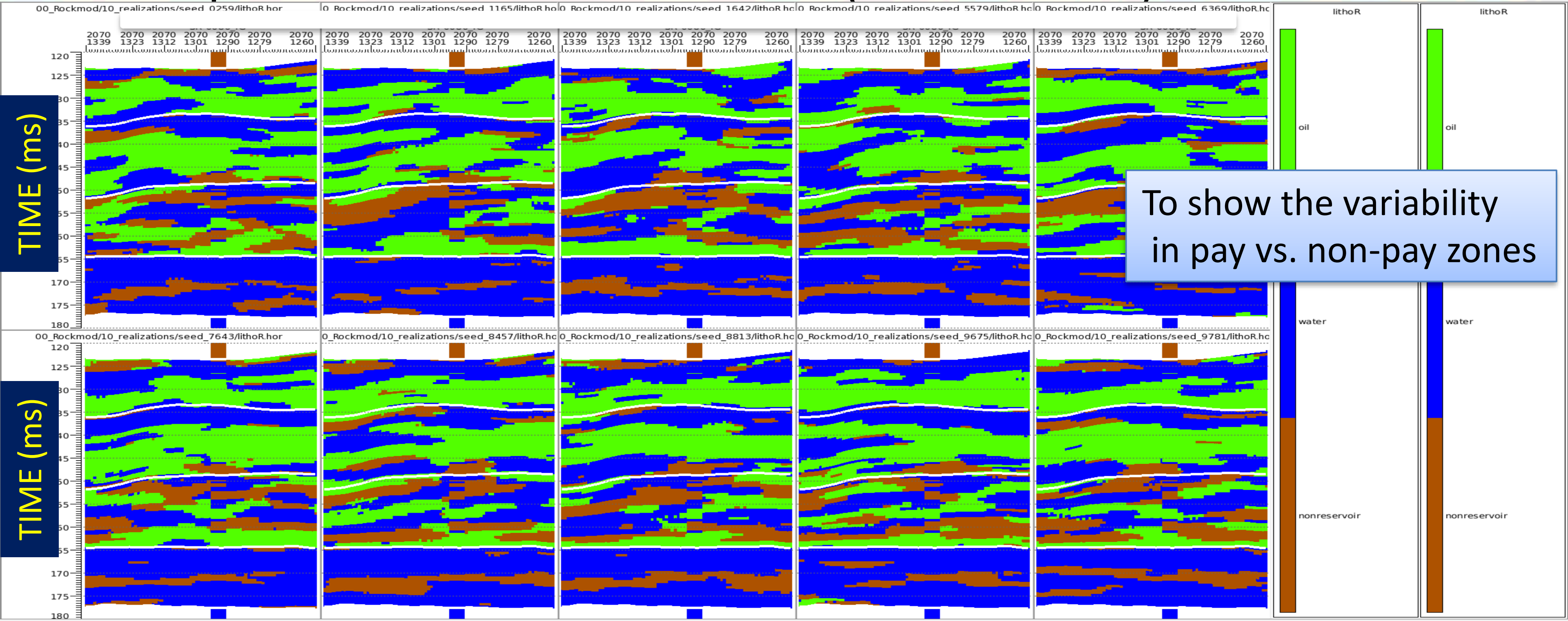
Simultaneous Geostatistical Inversion Outputs

- Single realization:
  - Lithology model
  - Property models (P-impedance, Vp/Vs ratio & density)
  - Synthetics & residuals
  - QC maps (S/N ratio, cross-correlation, average layer properties & lithology probabilities etc.)
  - Other QCs (prior & posterior lithology proportions, prior & posterior property PDFs)
- Multiple realizations:
  - Multiple lithology models
  - Lithology probability models & “most probable” lithology model
  - Multiple property models (P-impedance, Vp/Vs ratio & density)
  - Minimum, maximum, mean & standard deviation property models

Simultaneous Geostatistical Inversion tests – Unconstrained & constrained inversion

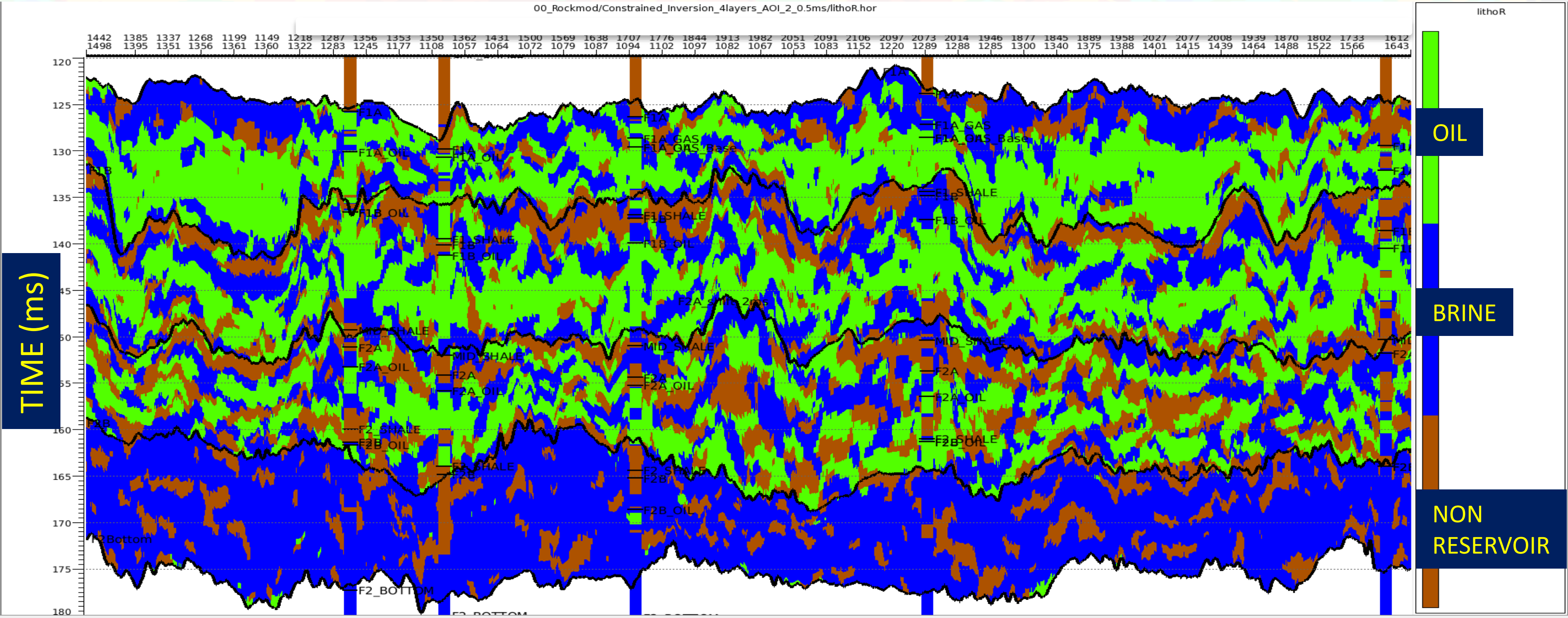


Simultaneous Geostatistical Inversion
Multiple realizations over test area (around SR-8x)

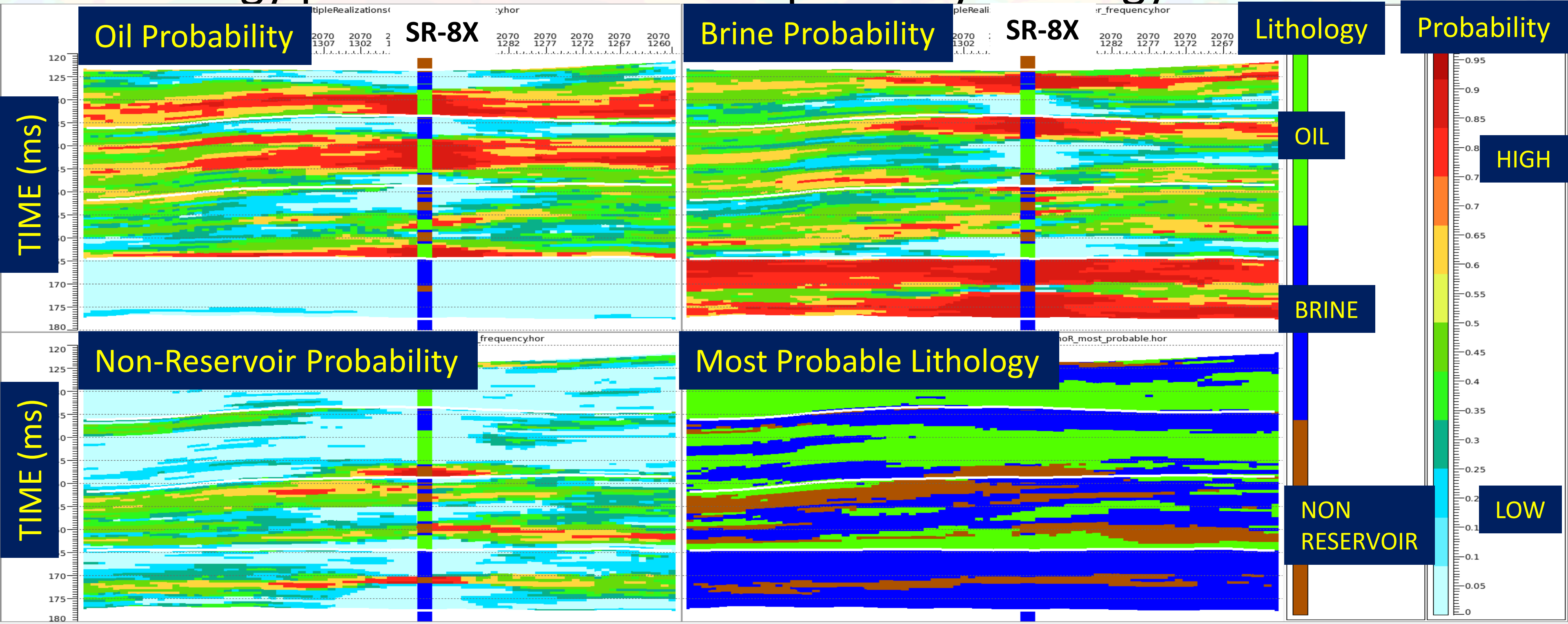


To show the variability in pay vs. non-pay zones

Simultaneous Geostatistical Inversion
Constrained inversion over full area



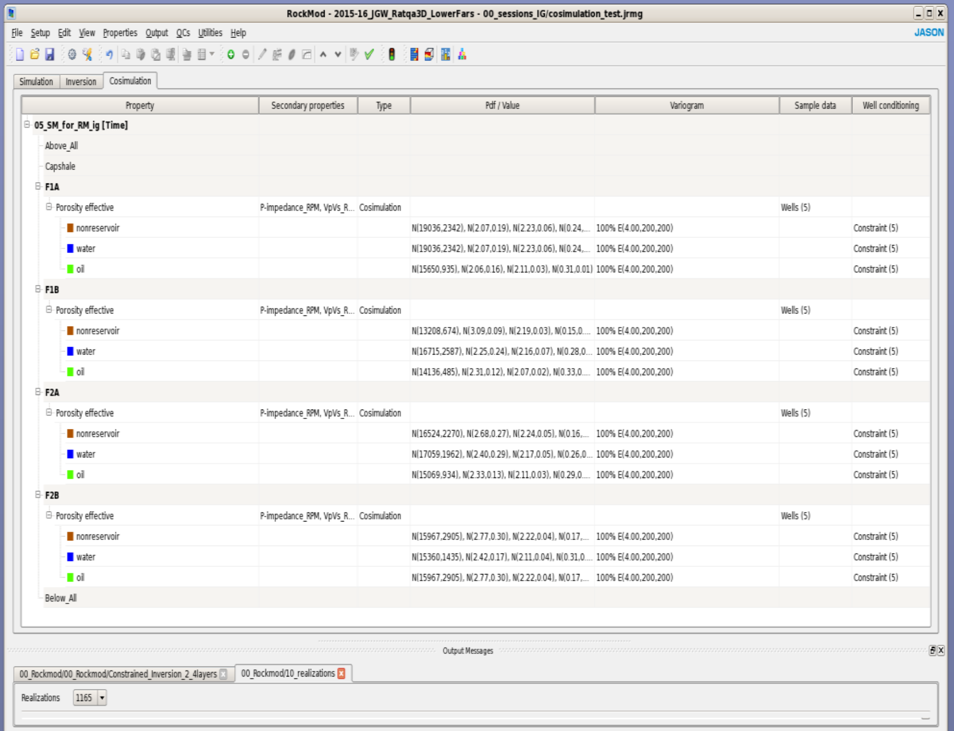
Simultaneous Geostatistical Inversion
Lithology probabilities and most probably lithology

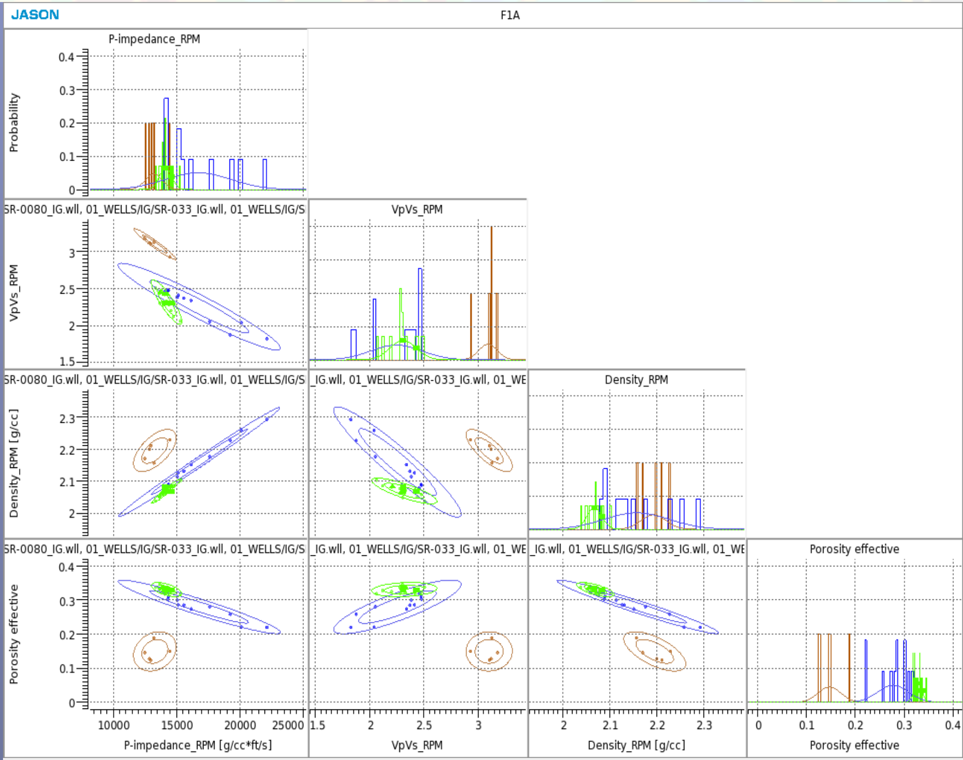


Next steps

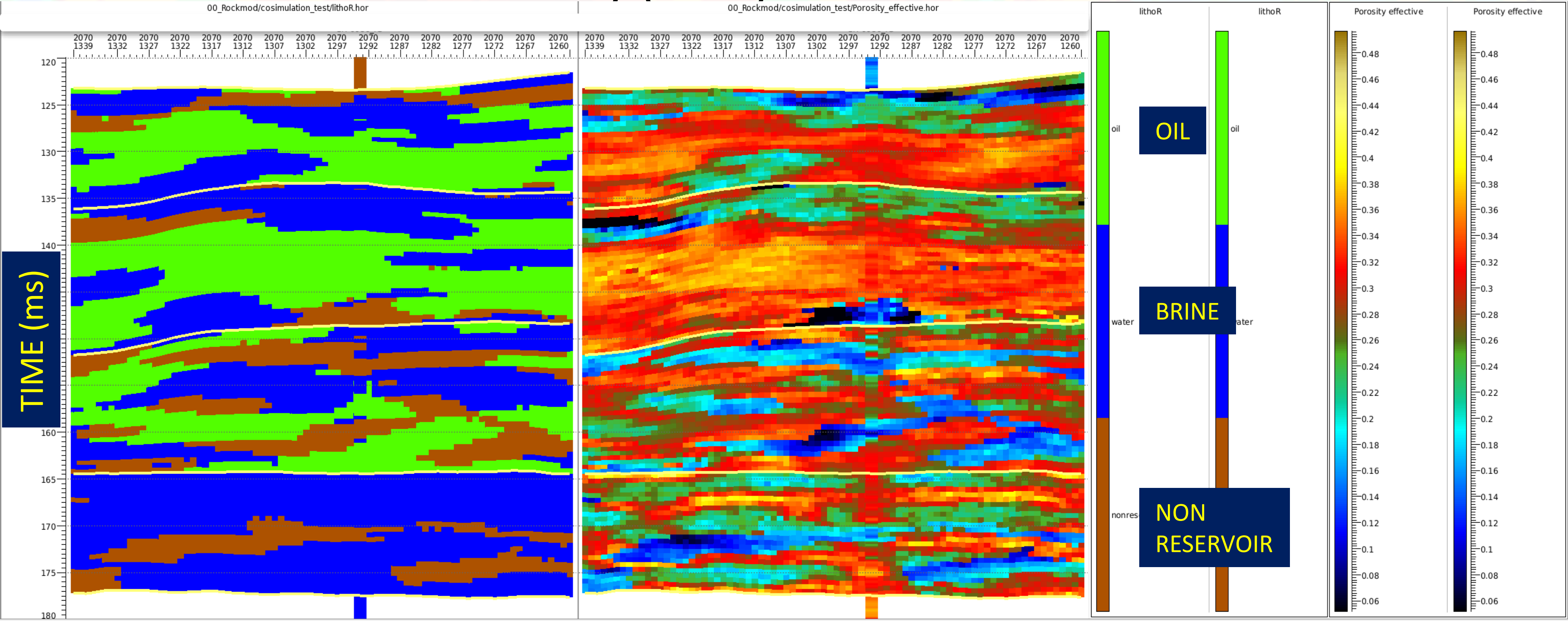
- Multiple realizations over full 3D area
- Model ranking, e.g. lithology connectivity
- Co-simulation using selected models, e.g. porosity
- Co-simulation model ranking, e.g. volumes at target locations

Simultaneous Geostatistical Inversion Cosimulation for Porosity (PHIE)





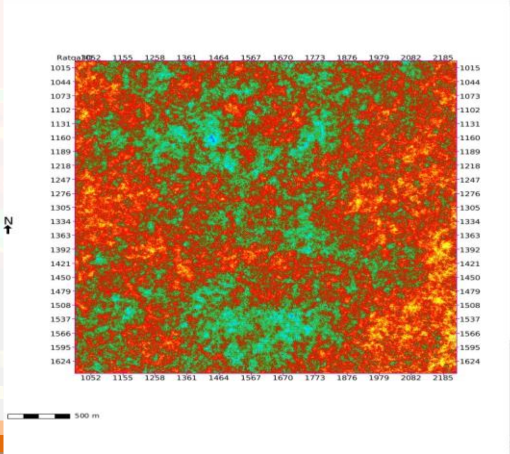
Simultaneous Geostatistical Inversion Cosimulation for Porosity (PHIE)



Cosimulation for Model Ranking - Volume of Pay

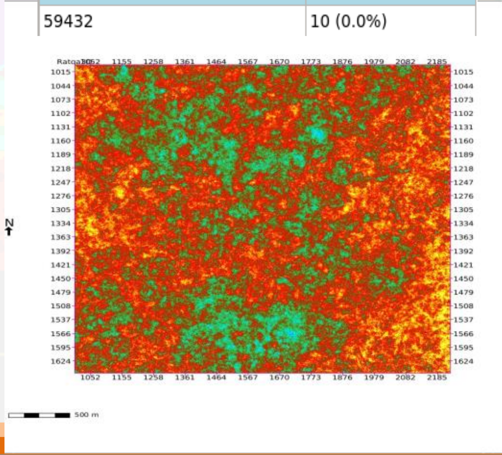
P90

Criterion1 [acre*ms]	Rank
59539	1 (100.0%)
59535	2 (88.9%)
59530	3 (77.8%)
59502.8	4 (66.7%)
59499.3	5 (55.6%)
59455.1	6 (44.4%)
59452.2	7 (33.3%)
59447.6	8 (22.2%)
59443	9 (11.1%)



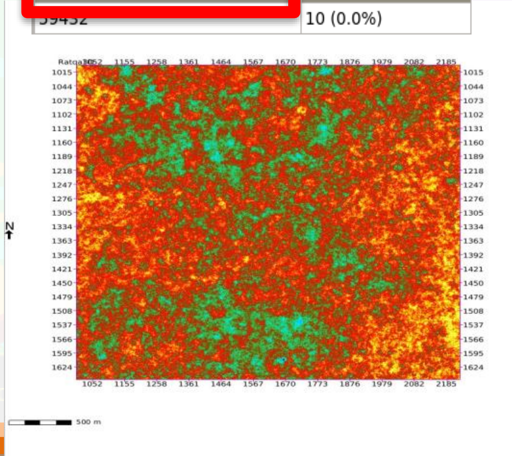
P50

Criterion1 [acre*ms]	Rank
59539	1 (100.0%)
59535	2 (88.9%)
59530	3 (77.8%)
59502.8	4 (66.7%)
59499.3	5 (55.6%)
59455.1	6 (44.4%)
59452.2	7 (33.3%)
59447.6	8 (22.2%)
59443	9 (11.1%)
59432	10 (0.0%)

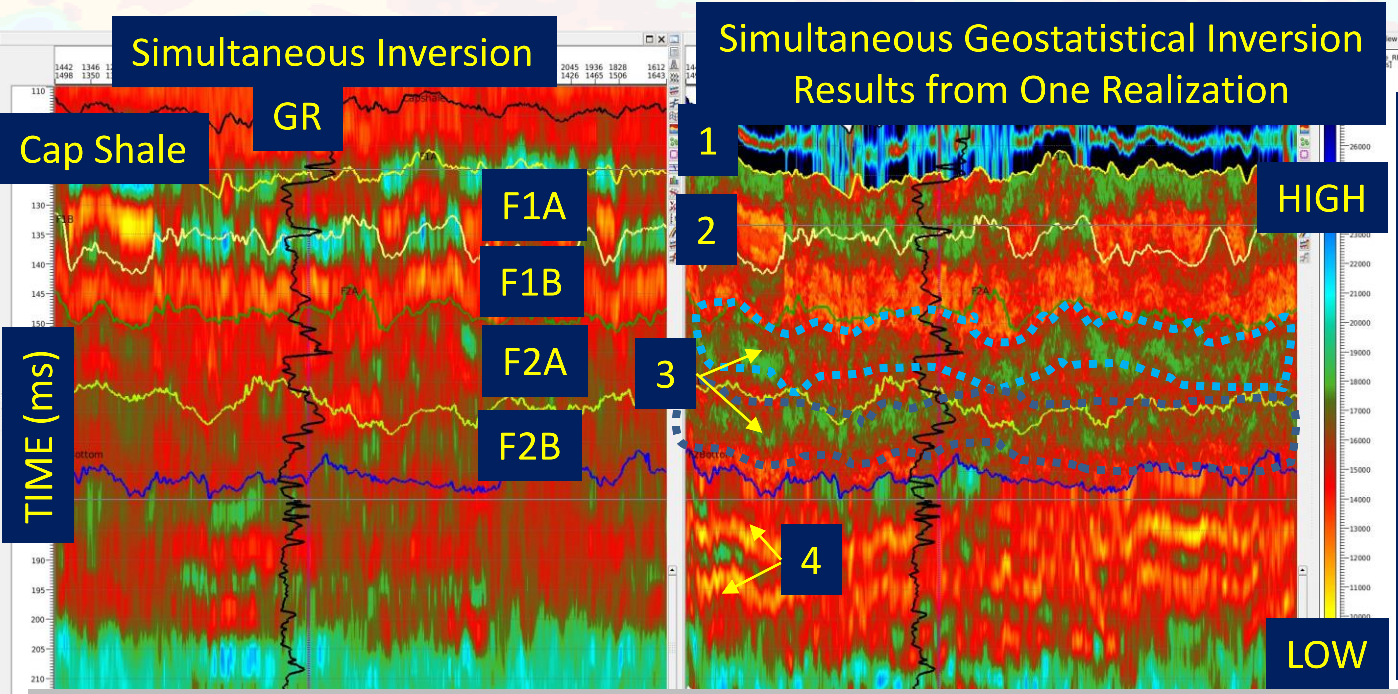


P10

Criterion1 [acre*ms]	Rank
59539	1 (100.0%)
59535	2 (88.9%)
59530	3 (77.8%)
59502.8	4 (66.7%)
59499.3	5 (55.6%)
59455.1	6 (44.4%)
59452.2	7 (33.3%)
59447.6	8 (22.2%)
59443	9 (11.1%)
59432	10 (0.0%)



Deterministic (2014) vs. Geostatistical Inversion (2018)

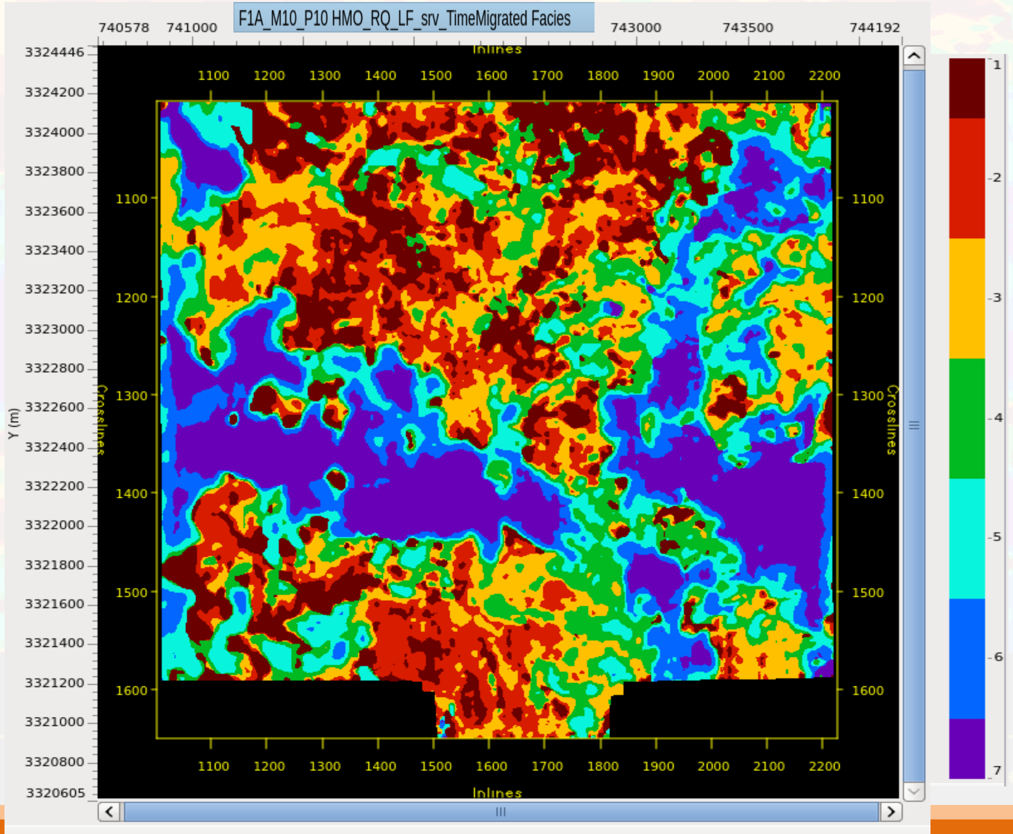


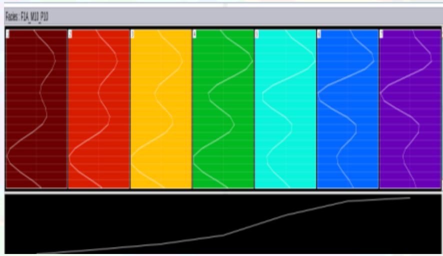
1. Cap Shale has been delineated properly.
2. The low acoustic impedance In F1A appears as two different properties.
3. Shale barriers within F2A & F2B have been Delineated.
4. Deeper features captured.

Two sections through the inverted volumes with Gamma Ray overlay, areas of low impedances are in warm colors.

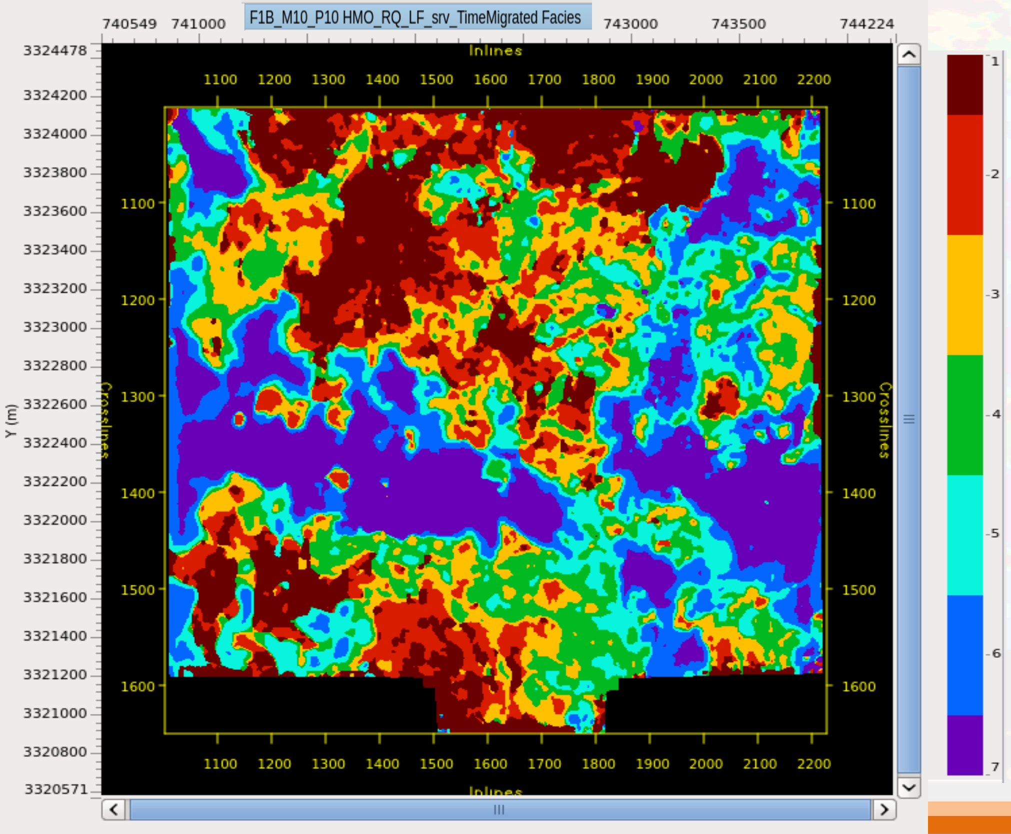
Seismic Facies Classification of Lower Fars F1A Layer (+/-10ms)

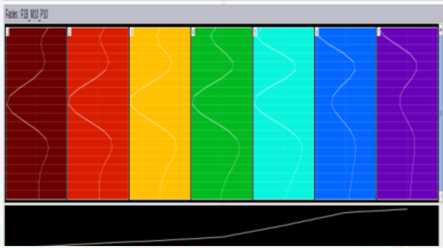
The interval covers the channel system +/-10ms, and required fewer classes for the facies classification



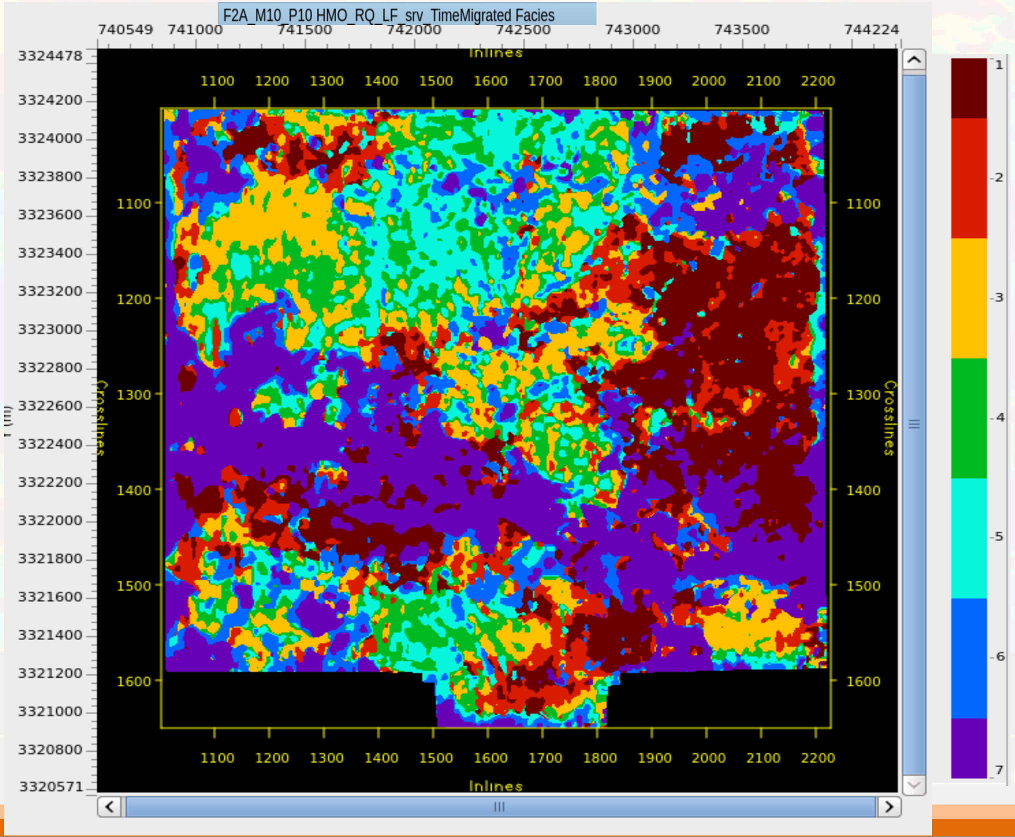


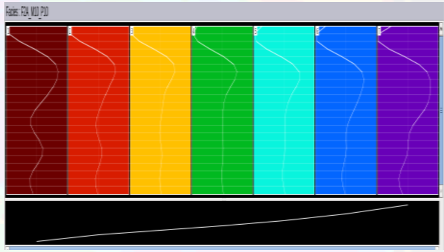
Seismic Facies Classification of Lower Fars F1B Layer (+/-10ms)



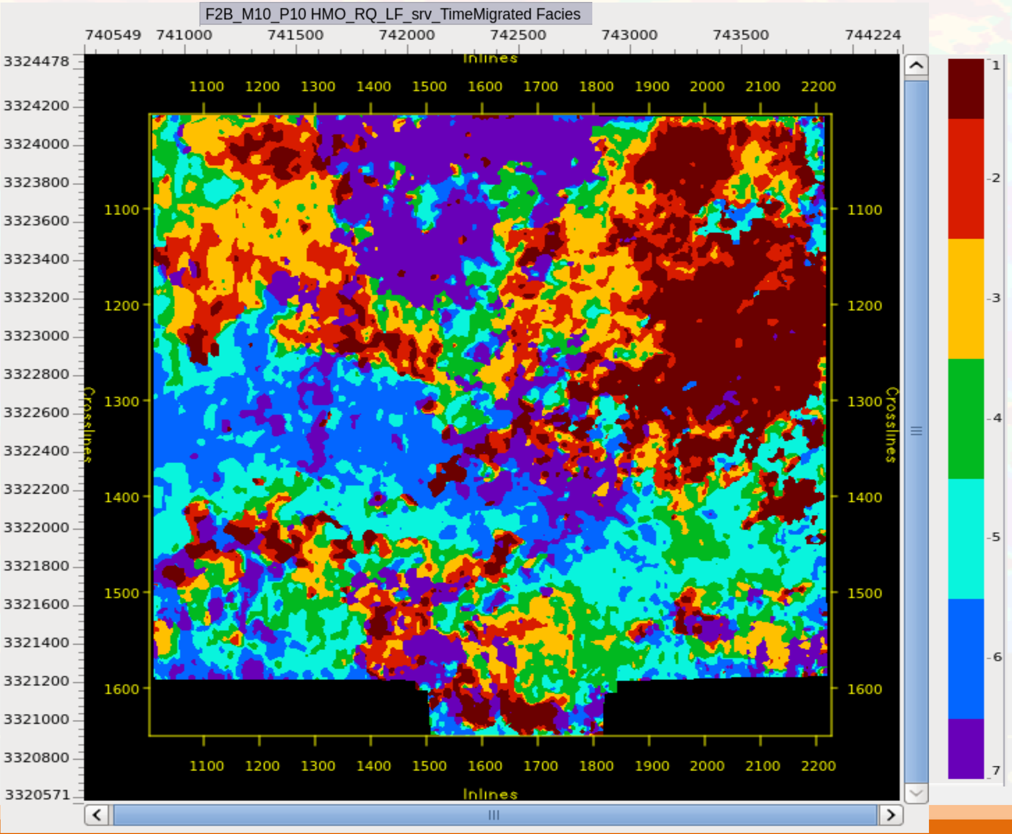


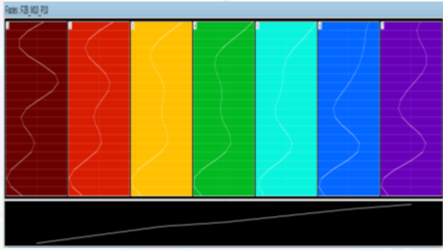
Seismic Facies Classification of Lower Fars F2A Layer (+/-10ms)



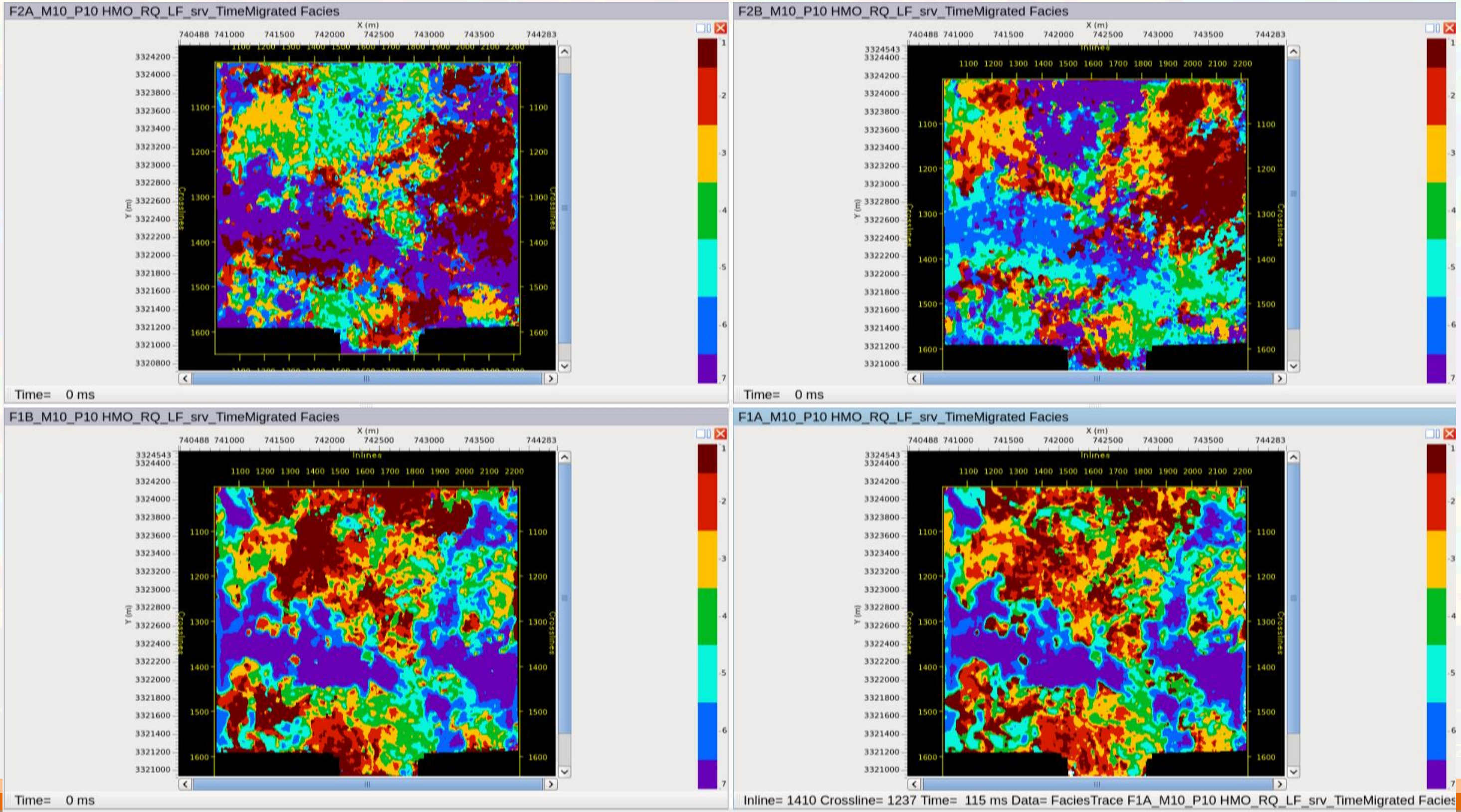


Seismic Facies Classification of Lower Fars F2B Layer (+/-10ms)





Seismic Facies Classification of Lower Fars All Layers (+/-10ms)



CONCLUSIONS

- Simultaneous geostatistical inversion (SGI) added much value in terms of delineating the shale barriers and enhancing resolution, in addition to estimating effective porosity for well releases
- For the success of the seismic inversion, good enough angle ranges is a necessity and the signal-to-noise ratio is a vital consideration.
- Multiple realizations from SGI gave us different scenarios which enhances our understanding of reservoir variability and its structure.
- Seismic facies classification assisted in identifying the channel geometry by classifying the shape of the seismic signal and mapping them across the survey.

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