A Probabilistic Approach to Solving Static Subsurface Uncertainty: Examples from Angola Block 0 Reservoirs*

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Abstract

The Pinda Formation in Angola's Block 0 has historically been described as a highly heterogeneous mixed clastic carbonate system that yields complex yet prolific reservoirs, for which rock quality is challenging to predict. Deterministic static modeling techniques have historically been employed to resolve Pinda subsurface uncertainty. Lately the use of probabilistic methods has grown in use and rather than providing a unique solution to subsurface uncertainty, they provide a range of possible outcomes.

Key static subsurface uncertainties associated with Pinda reservoirs in Block 0 have been identified and can be summarized into two questions: how much oil is there? (Original Oil in Place) and how easily will it move around? (Reservoir Connectivity). Thus OOIP and Reservoir Connectivity have been carried as key uncertainty parameters in this study.

The probabilistic approach taken uses an existing deterministic geologic model (base case) as the starting point, from which low and high scenarios are created. Five model variables were found to significantly affect OOIP and Reservoir Connectivity: External Porosity Histogram, Global Facies Proportions, Average Porosity Trend Map, Variogram Length, and Porosity Trend Map Weighting. Uncertainty ranges (scenarios) for those variables have been developed using a variety of statistically valid methods. Then permutations of all OOIP/connectivity scenarios have been combined to produce nine geologic model permutations. Those are then Scaled Up and subjected to dynamic flow simulation. We present a thorough discussion of the statistical methods employed to generate uncertainty variable ranges and the probabilistic approach workflow.

A Probabilistic Approach to Solving Static Subsurface Uncertainty:

Examples from Angola Block 0 Reservoirs

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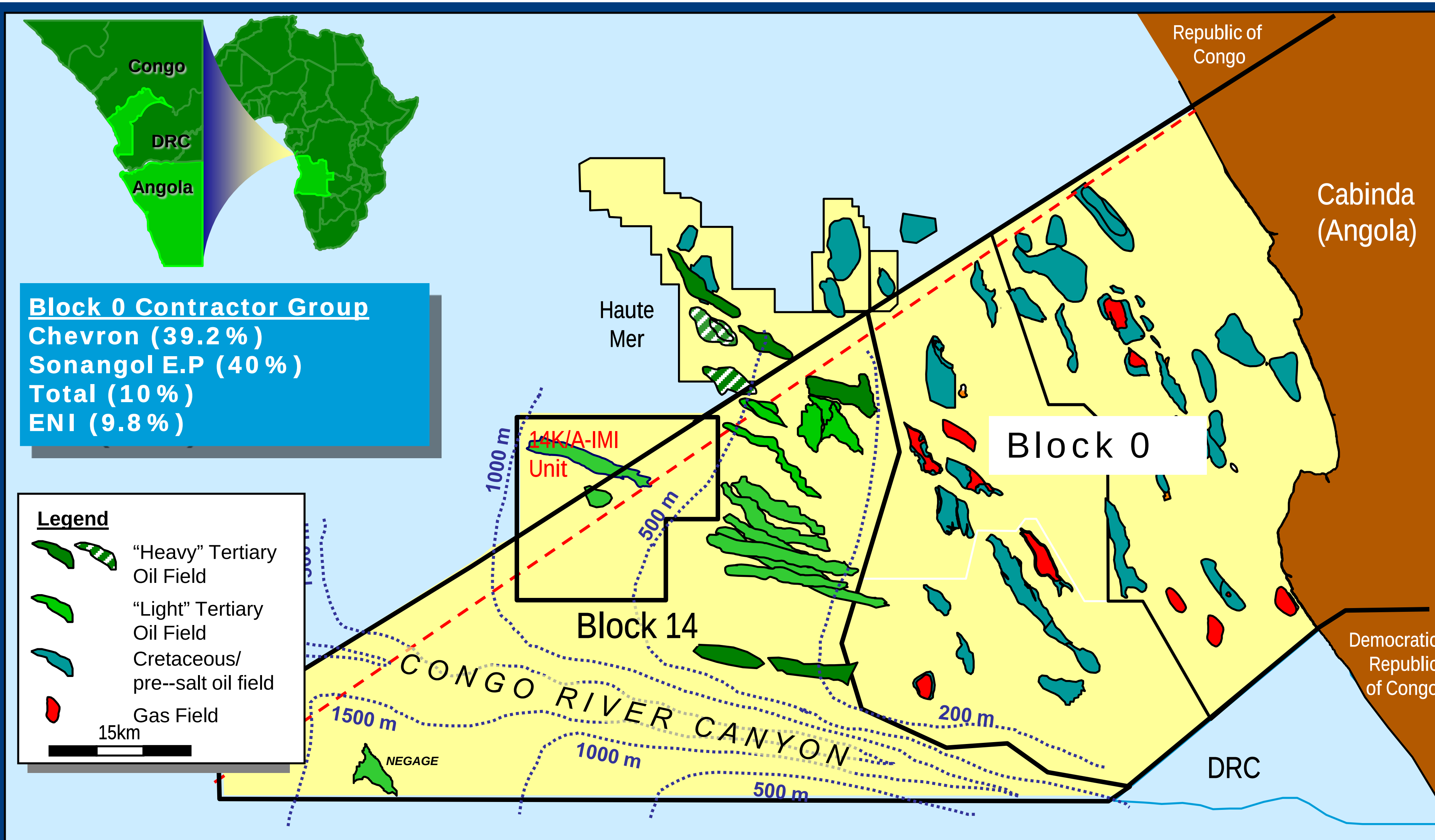
Presentation Outline

- Regional Background Information
- Problem Statement
- Identifying Uncertainty Parameters & Variables
- Developing Uncertainty Ranges
- Property Simulation
- Model Performance
- Summary of Results
- Acknowledgements

Regional Background

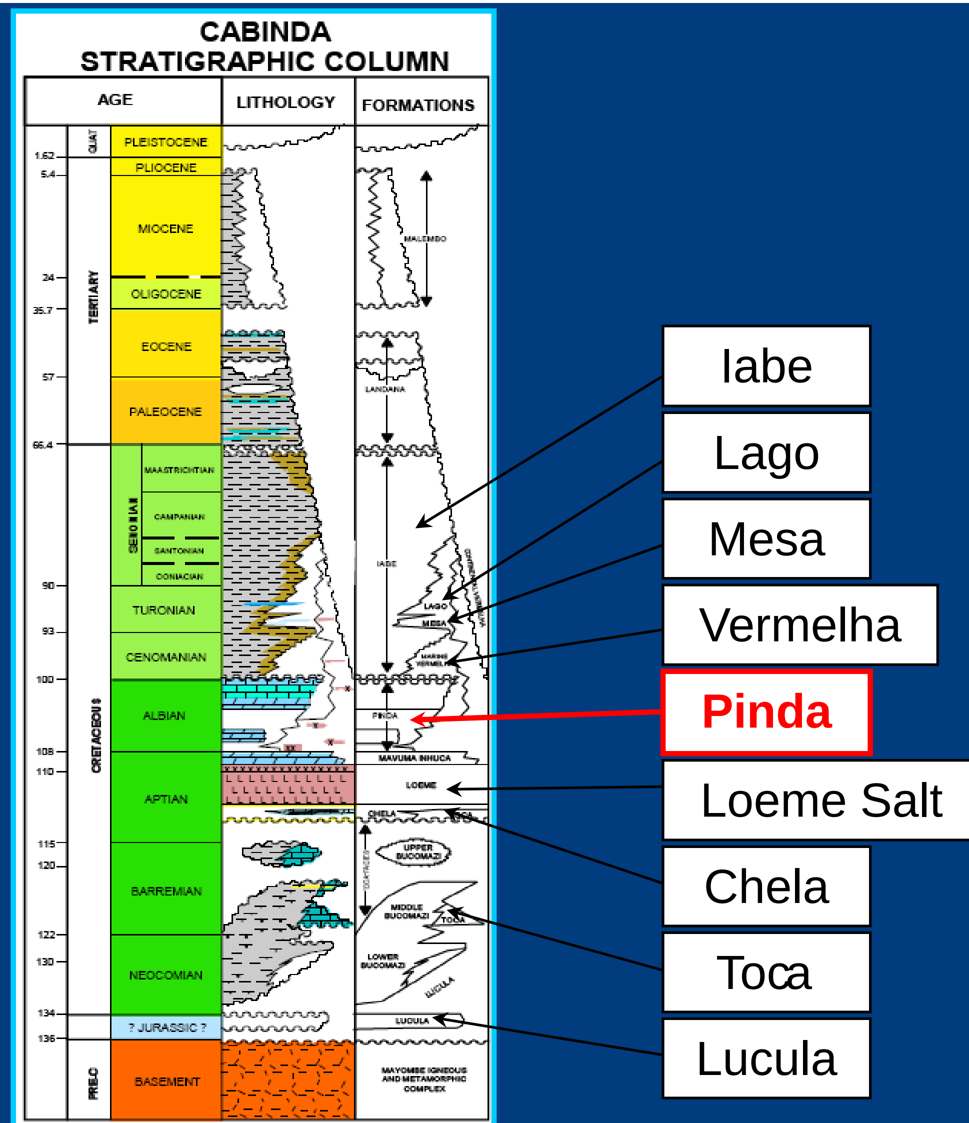
Offshore Cabinda Oilfields & Licenses

Block 0 Contractor Group
Chevron (39.2%)
Sonangol E.P (40%)
Total (10%)
ENI (9.8%)



Cabinda Stratigraphic Column

The Albian Age Pinda Formation is a mixed clastic-carbonate system and is the oldest of the post-salt reservoirs. It is also the second most prolific (second to Vermelha) formation in the Cabinda, Block 0 concession.



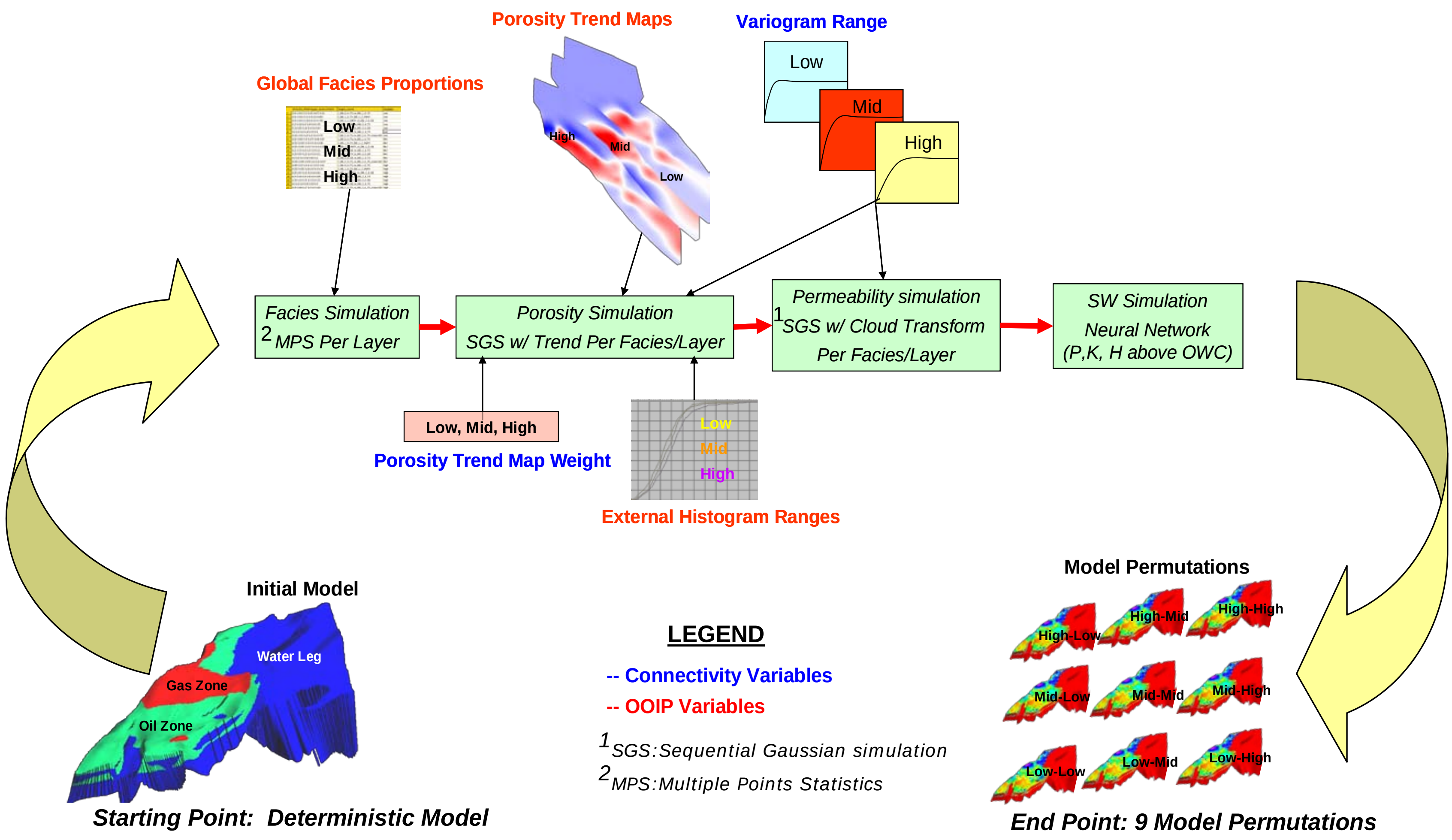
Problem Statement

- The Pinda Formation in Angola's Block 0 has historically been described as a highly heterogeneous mixed clastic carbonate system that yields complex yet prolific reservoirs, for which rock quality is challenging to predict.

- Key static subsurface uncertainties associated with Pinda reservoirs in Block 0 have been identified and can be summarized into two questions:
  - *how much oil is there*? **(Original Oil in Place)**
  - *how easily will it move around*? **(Reservoir Connectivity)**.

Solving Subsurface Uncertainty

Modeling Workflow



Identifying Uncertainty Variables

Selected Variables Affecting OOIP :

- External Histograms (for porosity)
- Global Facies Proportions
- Average Porosity Trend Maps

Selected Reservoir Connectivity Variables:

- Variogram Length (short,mid,long)
- Porosity Trend Map Weighting (input variable for SGS w/ trend)

Developing Uncertainty Ranges:

Variables Affecting Original Oil In Place

REMINDER:

- External Histograms (for porosity)
- Global Facies Proportions
- Average Porosity Trend Maps

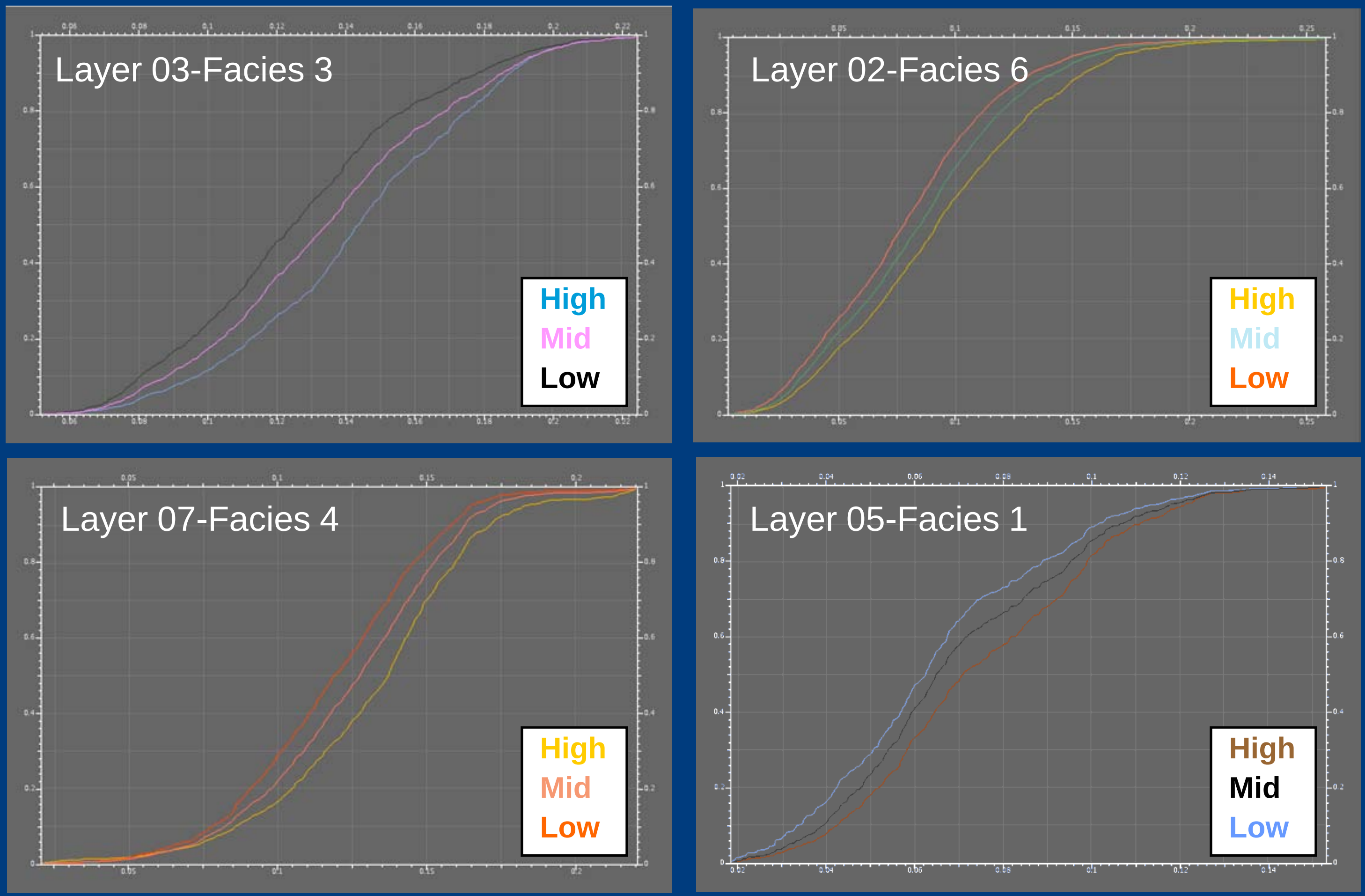
Developing External Histogram Ranges

Methodology:

- Porosity external histograms have been computed from well logs in Gocad.
- Low and high estimates have been developed by adding pseudo-wells with pessimistic and optimistic average porosity values respectively.

Developing External Histogram Ranges

Selected Examples of External Histograms



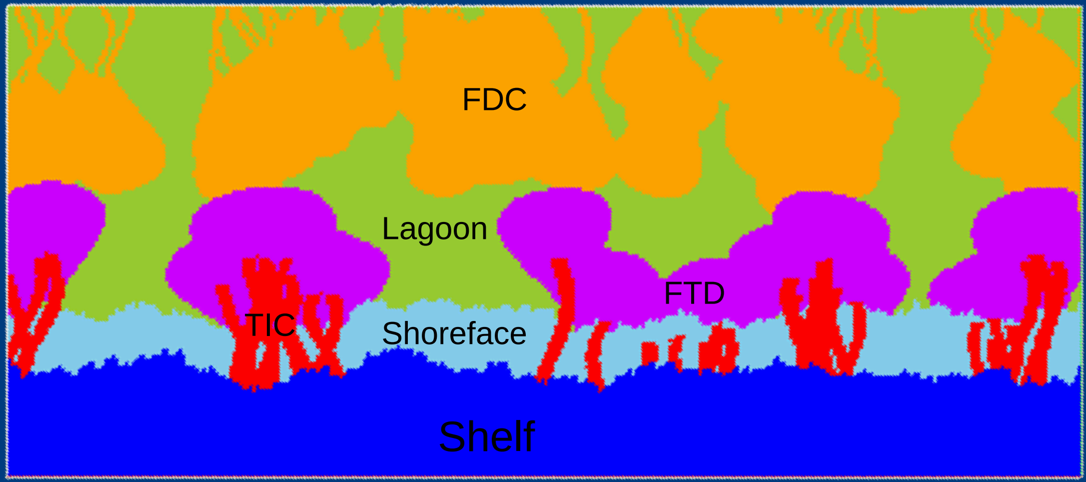
Created external histograms by facies and by layer for 7 major reservoir layers.

Developing Global Facies Proportion Ranges

Six depositional facies have been identified from core and modeled :

- Facies 1(TIC)- Tidal Inlet Channel
- Facies 2 (FTD)- Flood Tidal Deltas
- Facies 3 (FDC)- Fluvio-Distributary Complex
- Facies 4 – Shoreface
- Facies 5- Shelf (non reservoir)
- Facies 6- Lagoon (non reservoir)

Model Facies Training Image



Developing Global Facies Proportion Ranges

Methodology:

- Estimates of low, mid and high facies proportions were developed for each of the seven major model layers
- Mid facies proportions were taken directly from well facies data.
- Low and high range estimates have been developed using a rationale that involved lowering and increasing the reservoir/non-reservoir ratio.

SAMPLES	LAYER 2	DATA (%)	LOW			MID			HIGH		
			Target	Simulated	Delta	Target	Simulated	Delta	Target	Simulated	Delta
247	**TIC**	2.5	1	1.1	-0.1	1.5	1.2	0.3	2.5	1.9	0.6
	FTD	1.2	1.5	1.3	0.2	2.5	2	0.5	3	2.4	0.6
	FDC	15.8	12	12.7	-0.7	16	16.6	-0.6	20	21.1	-1.1
	SHOREFACE	0	0	0	0	0	0	0	0	0	0
	SHELF	0	0	0	0	0	0	0	0	0	0
	LAGOON	80.6	85.5	85	0.5	80	80.2	-0.2	74	74.7	-0.7

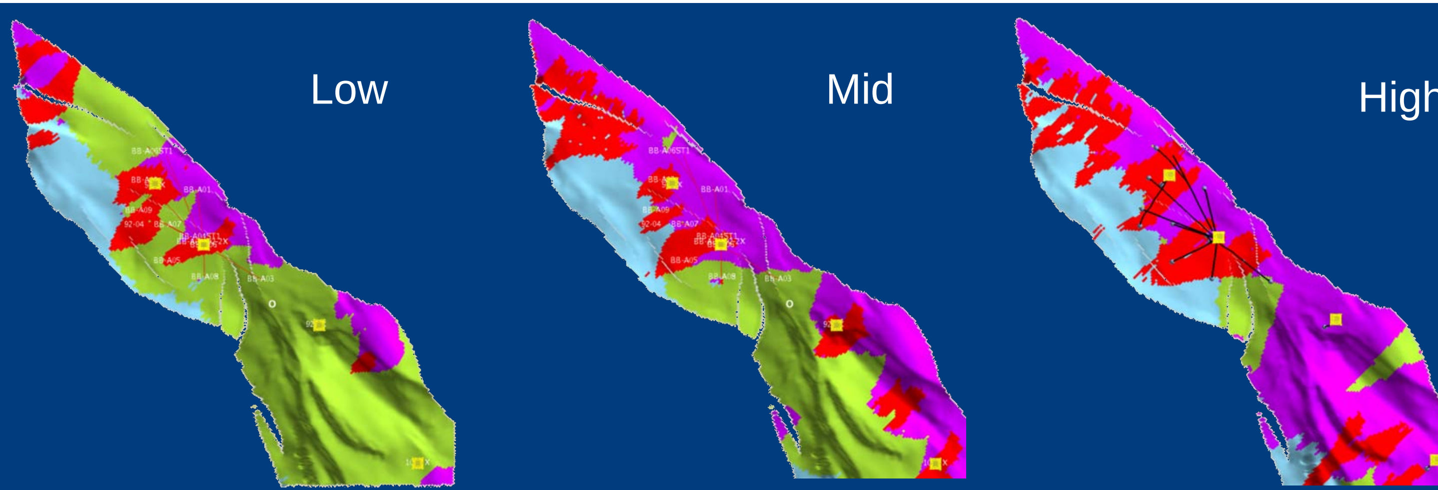
Example of a Facies proportion table.

Reservoir

Non Reservoir

Model Facies Maps

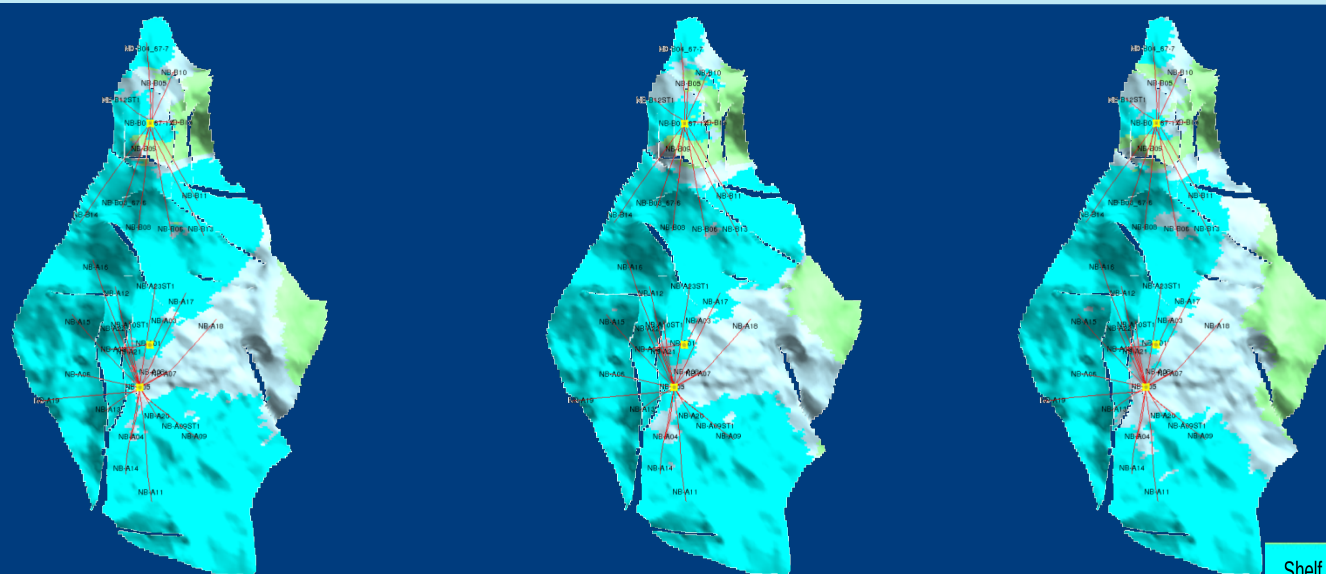
Reservoir #1



FACIES LEGEND

- TIC
- FTD
- FDC
- Shelf
- Lagoon
- Shoreface

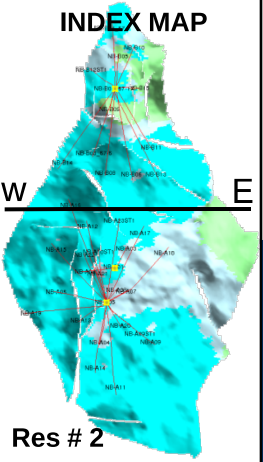
Reservoir # 2



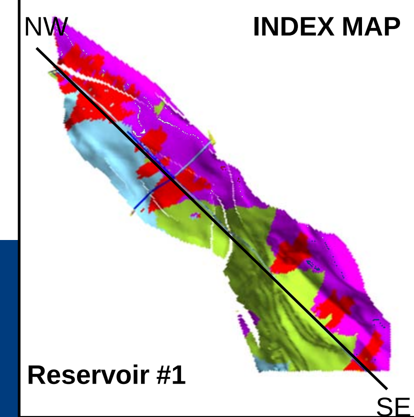
Model Layer 287
(just above PTS1)

FACIES LEGEND

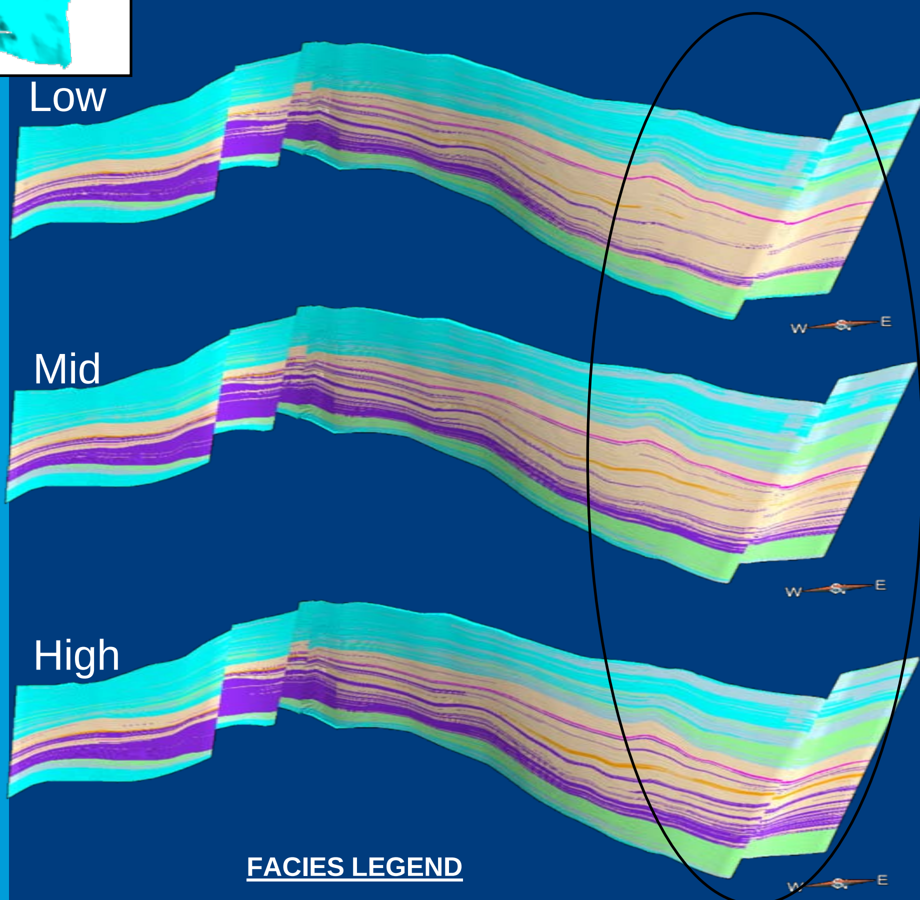
Shelf	Sandy shelf	Shoreface	Lagoon	Tidal	Fluvio	Anhydrite



Model Facies Cross-Sections



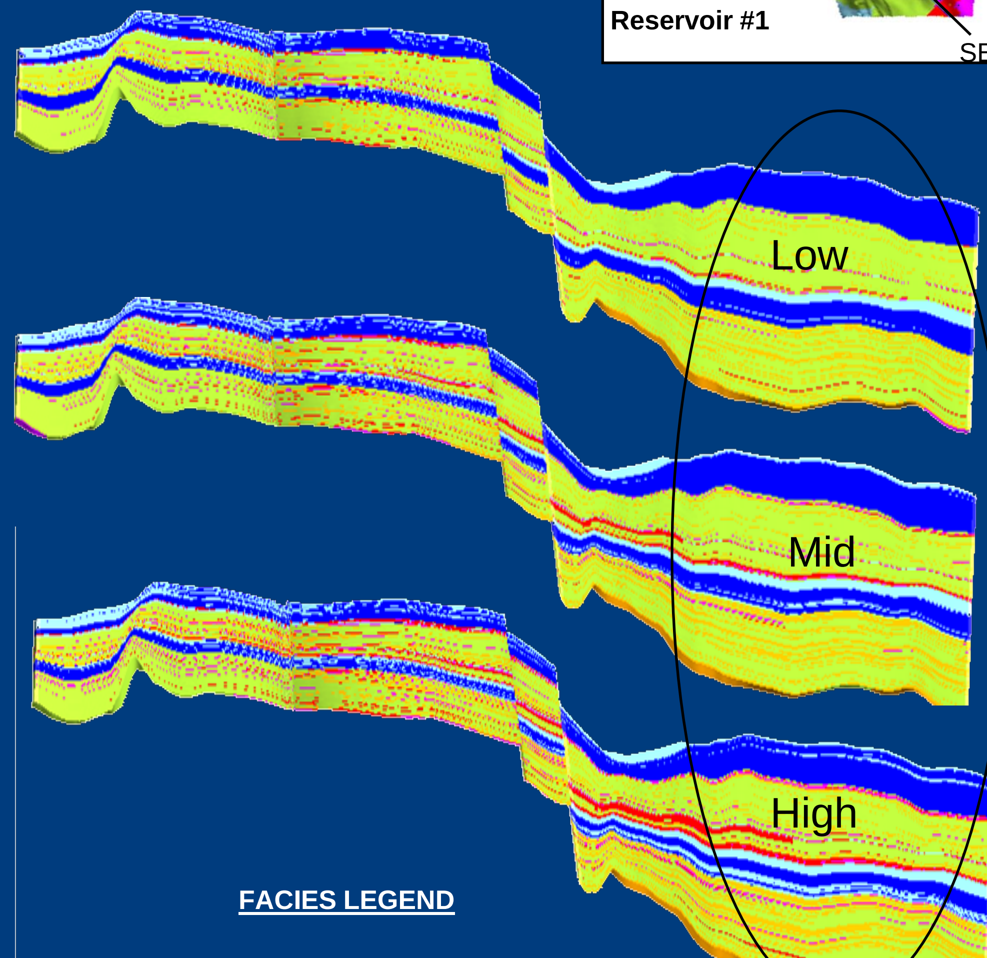
Reservoir # 2 -East Cross Section



FACIES LEGEND

Shelf	Sandy shelf	Shoreface	Lagoon	Tidal	Fluvio	Anhydrite

Reservoir #1 NW-SE Cross Section



FACIES LEGEND

TIC	FTD	FDC	Shelf	Lagoon	Shoreface

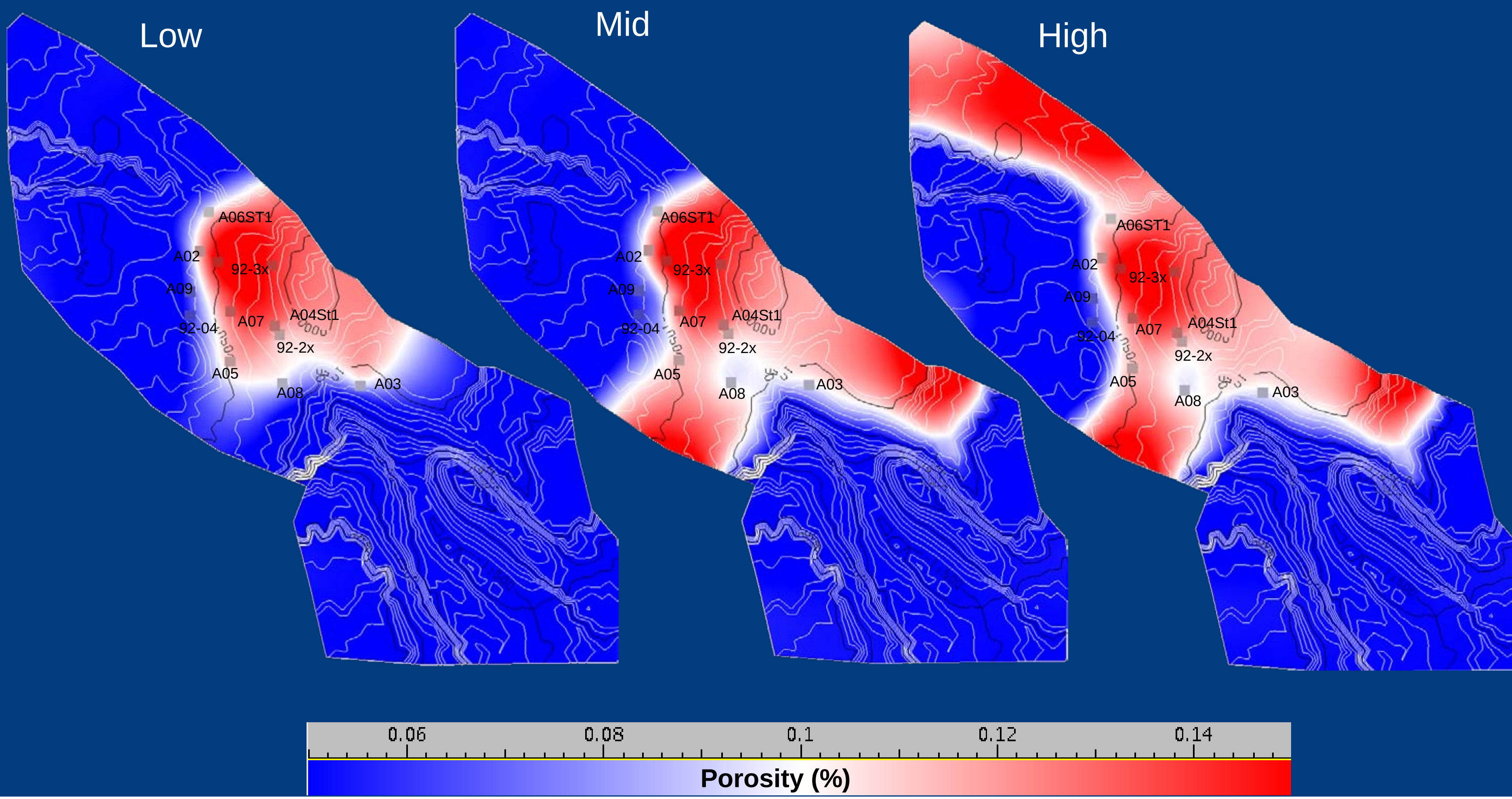
Developing Porosity Trend Maps

Methodology:

- Created average porosity maps from well log data for 20 model layers. Such maps provided the basis for mid case porosity trend maps.

- Then low and high porosity trend map cases have been developed by respectively lowering and increasing average reservoir porosity away from well control based on geologic interpretation.

Examples of Average Porosity Trend Maps



Developing Uncertainty Ranges:

Variables Affecting Reservoir Connectivity

REMINDER:

- Variogram Length (short, mid, long)
- Average Porosity Trend Map weighting (input variable for SGS)

Developing Semi-variogram Ranges

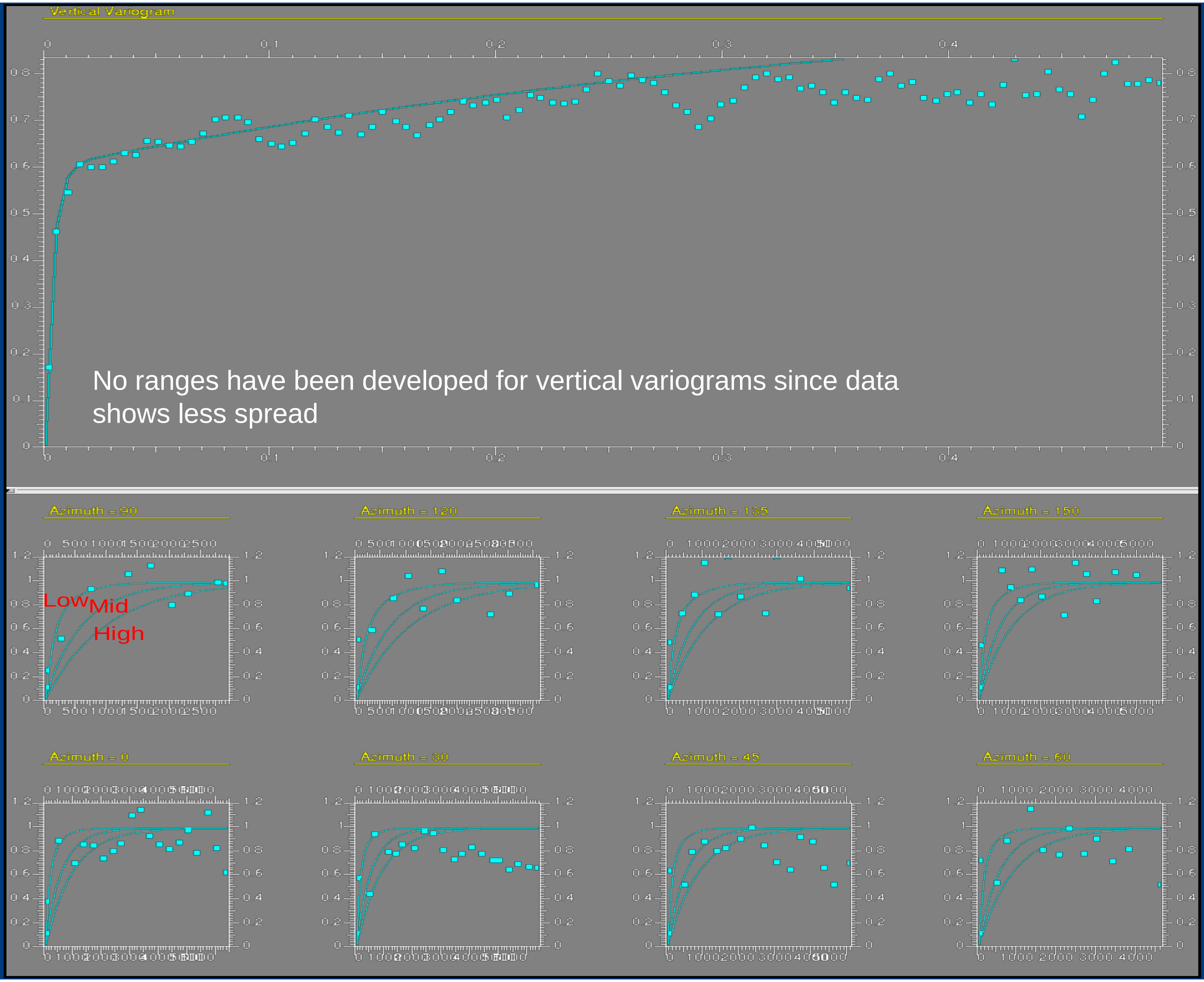
Methodology:

- Porosity semi-variograms have been built by facies in order to capture variability patterns pertaining to each facies.
- Mid range estimate has been assumed as the best possible fit to the well data
- Extreme (Lowest-shortest, highest-longest possible) range estimates (horizontal variograms only) have been developed by fitting well data pessimistically and optimistically respectively
- Realistic pessimistic and optimistic ranges have been handled by creating intermediate cases between extreme cases and respective mid variogram ranges.

Note: *variograms are used to simulate permeability and porosity*

Porosity Variography

Shelf Variograms



Average Porosity Trend Map Weightings

Previous Pinda reservoir study used porosity trend map weighting ranges of 10-30-50 %. However history matching trials showed that 30-50 % cases were lacking heterogeneity

Thus weightings of 5-10-15 % have been used in this study.

	$ Map_Weight	Con_Case
1	5	Low
2	10	Mid
3	15	High

Property Simulation

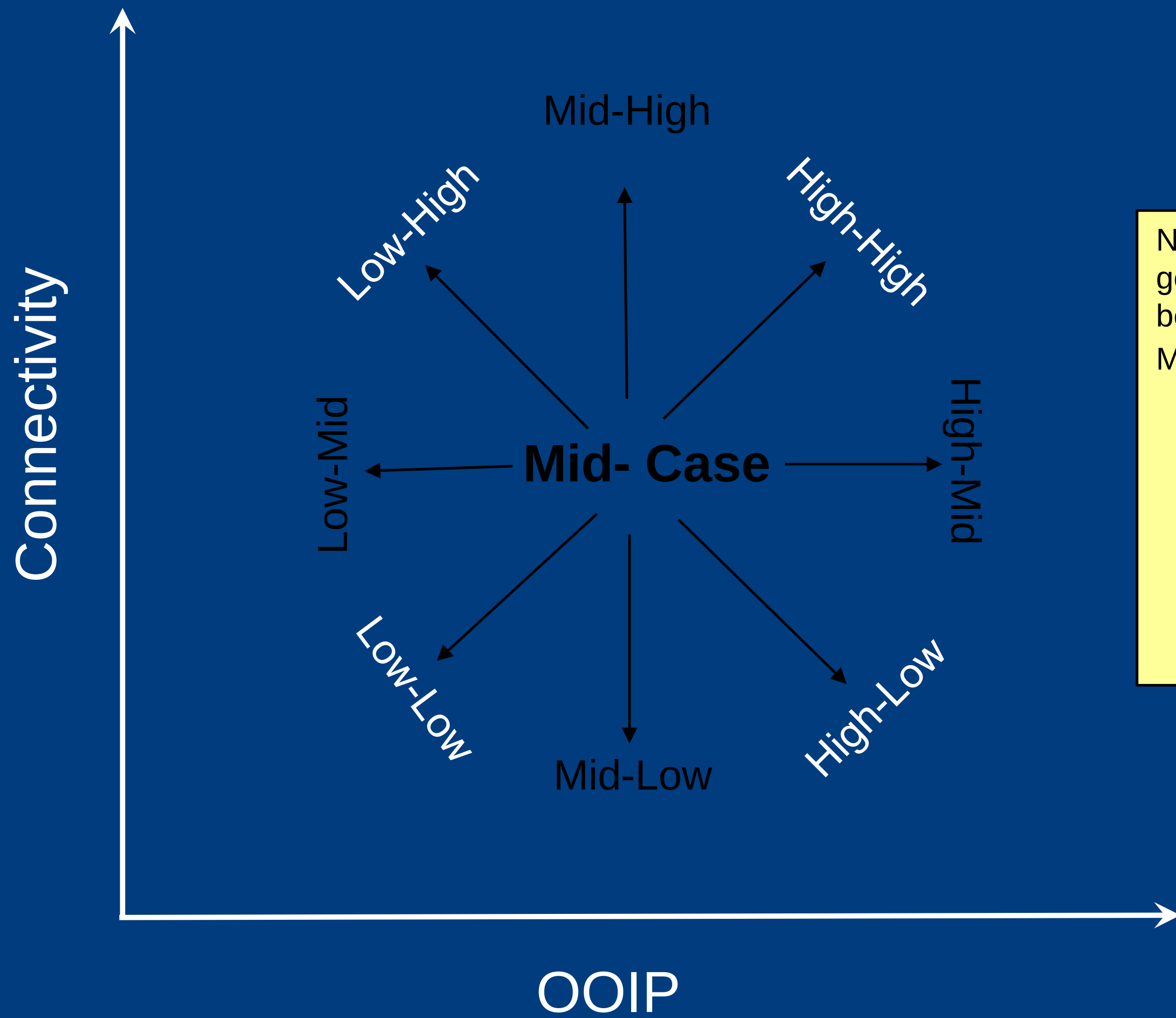
Experimental Design

Simplified Experimental Design Table

Run #	OOIP Variables	Connectivity Variables
1	Low	Low
2	Low	Mid
3	Low	High
4	Mid	Low
5	Mid	Mid
6	Mid	High
7	High	Low
8	High	Mid
9	High	High

Combined OOIP and Res. Connectivity variable scenarios in a Experimental Design table using the full factorial approach.

Model Permutations Chart



Nine model permutations have been generated but only the following five have been kept and carried into History Matching:

- **Low-High**
- **Low-Low**
- **Mid-Case**
- **High-High**
- **High-Low**

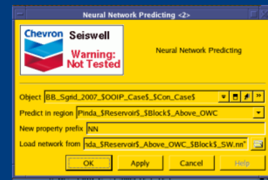
Property Simulation Workflow

ED Table

Run#	Connectivity Variables	OOIP Variables
1	Low	High
2	Mid	Low
3	High	Low
4	Low	High
5	Mid	Mid
6	High	Low
7	Low	High
8	Mid	High
9	High	Low

2

Property Simulator



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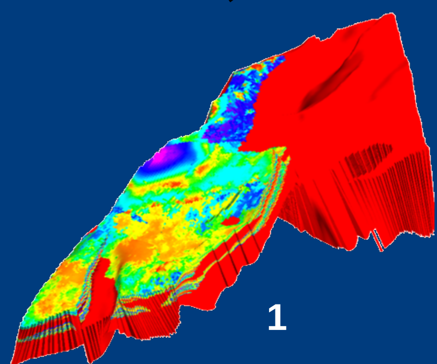

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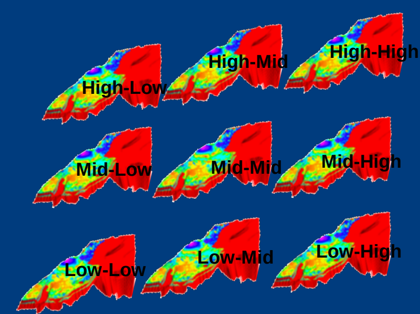
Starting Point: Deterministic Model



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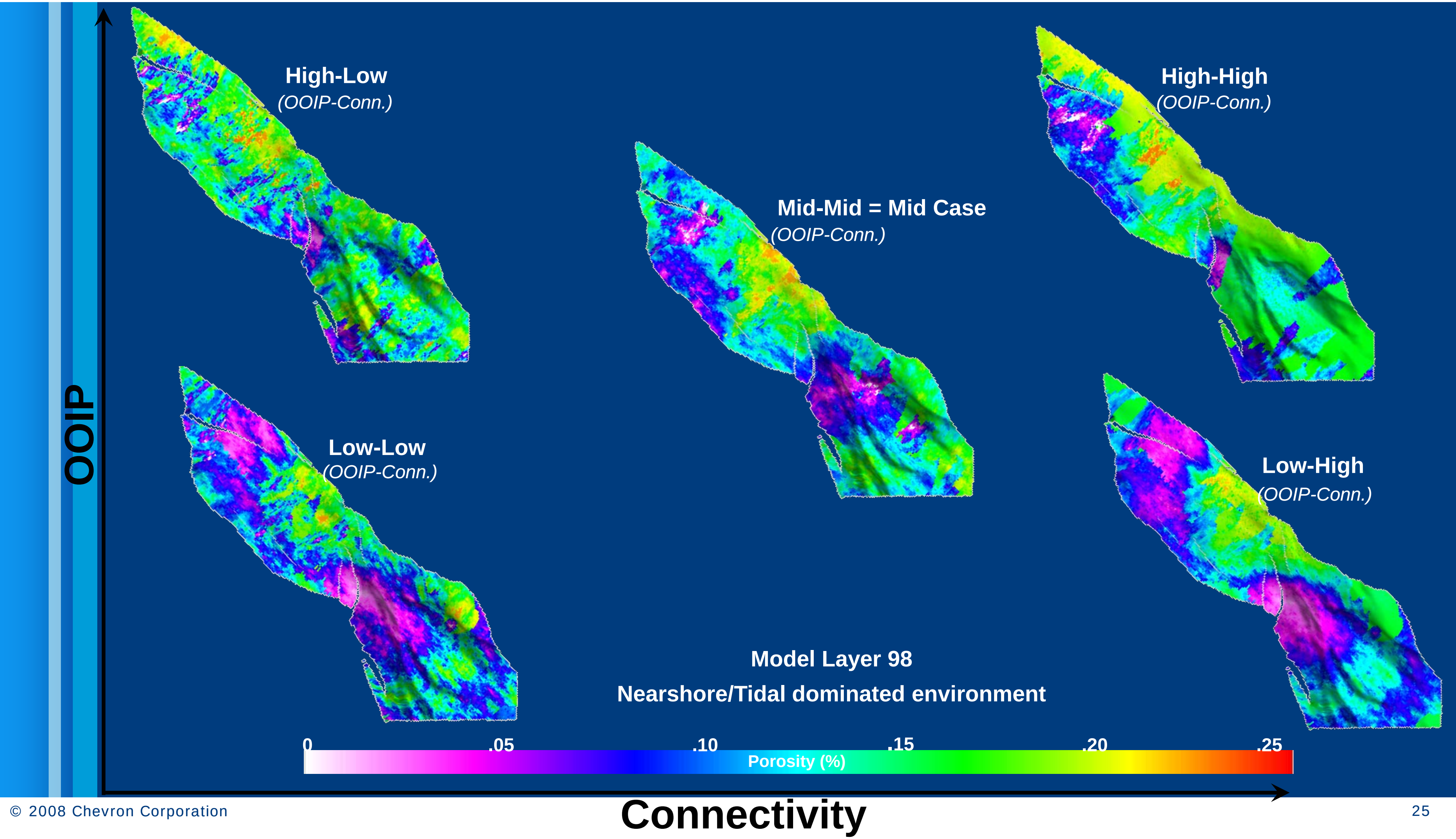
End Point: 9 Model Permutations

1. Used the deterministic model as input (***single realizations of res. properties***)
2. Combined low, mid, and high variable scenarios using ***Full Factorial ED***
3. Fed experimental design table into the Property simulator
   - ***Facies, porosity, perm and water saturation***
4. Nine model Permutations have been created:
   - **Low-Low**
   - **Low-Mid**
   - **Low-High**
   - **Mid-Low**
   - **Mid-Mid**
   - **Mid-High**
   - **High-Low**
   - **High-Mid**
   - **High-high**

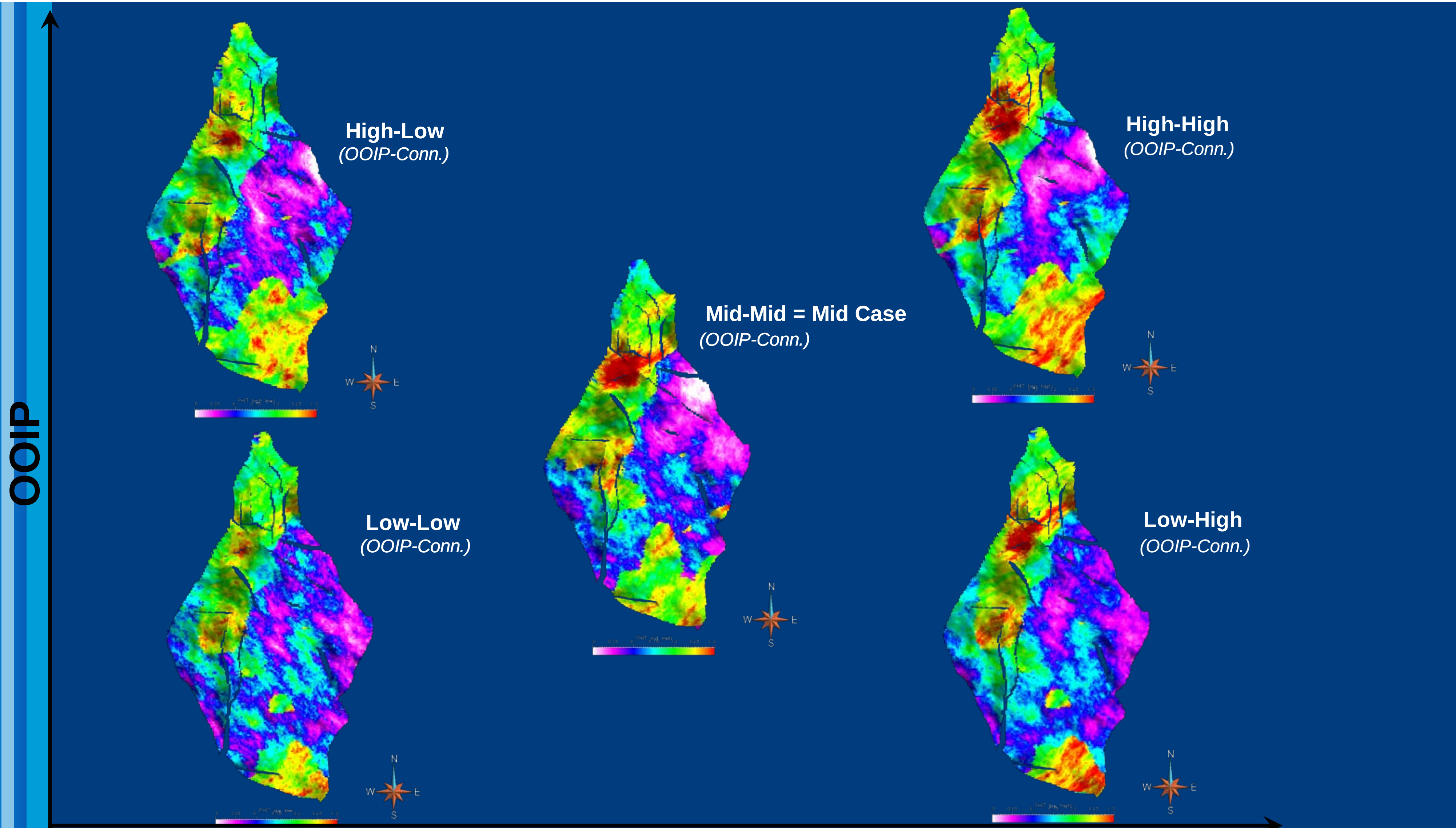
Model Porosity Maps

Reservoir # 1 Examples

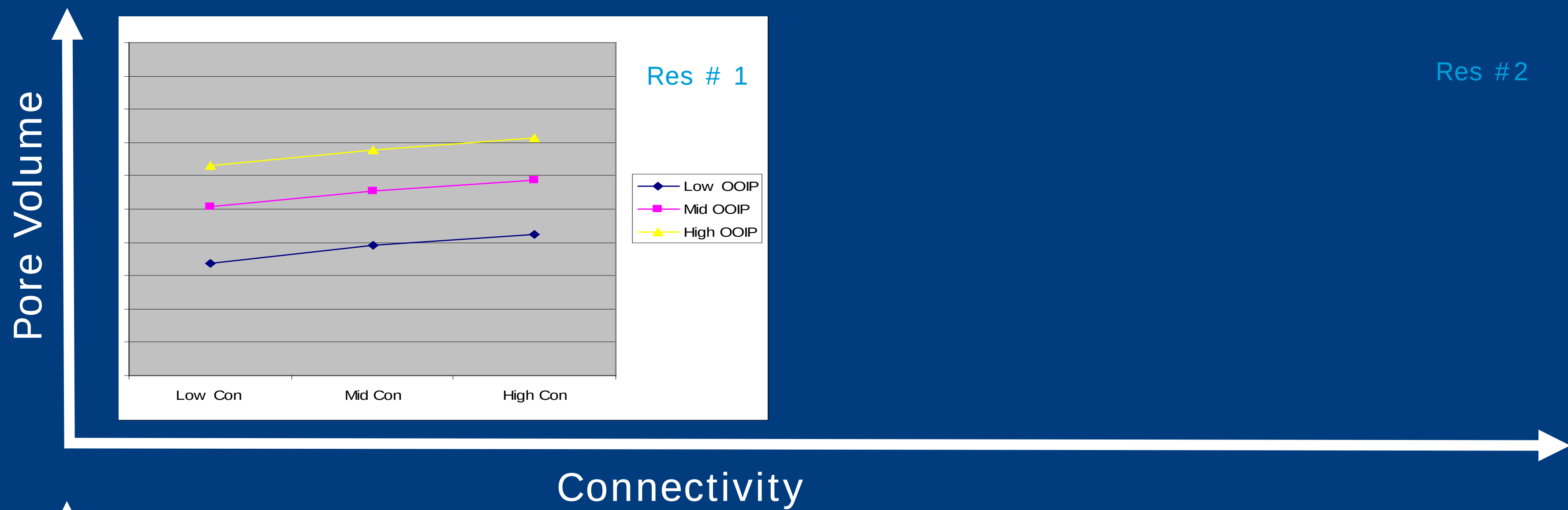


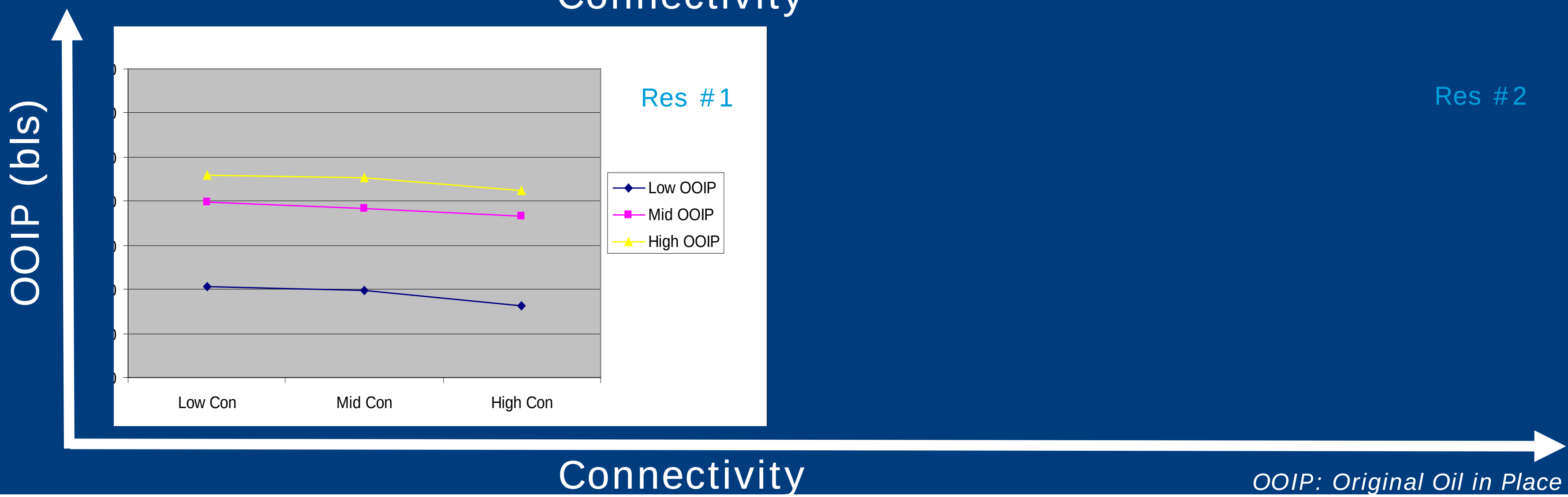
Model Porosity Maps

Reservoir # 2 Examples



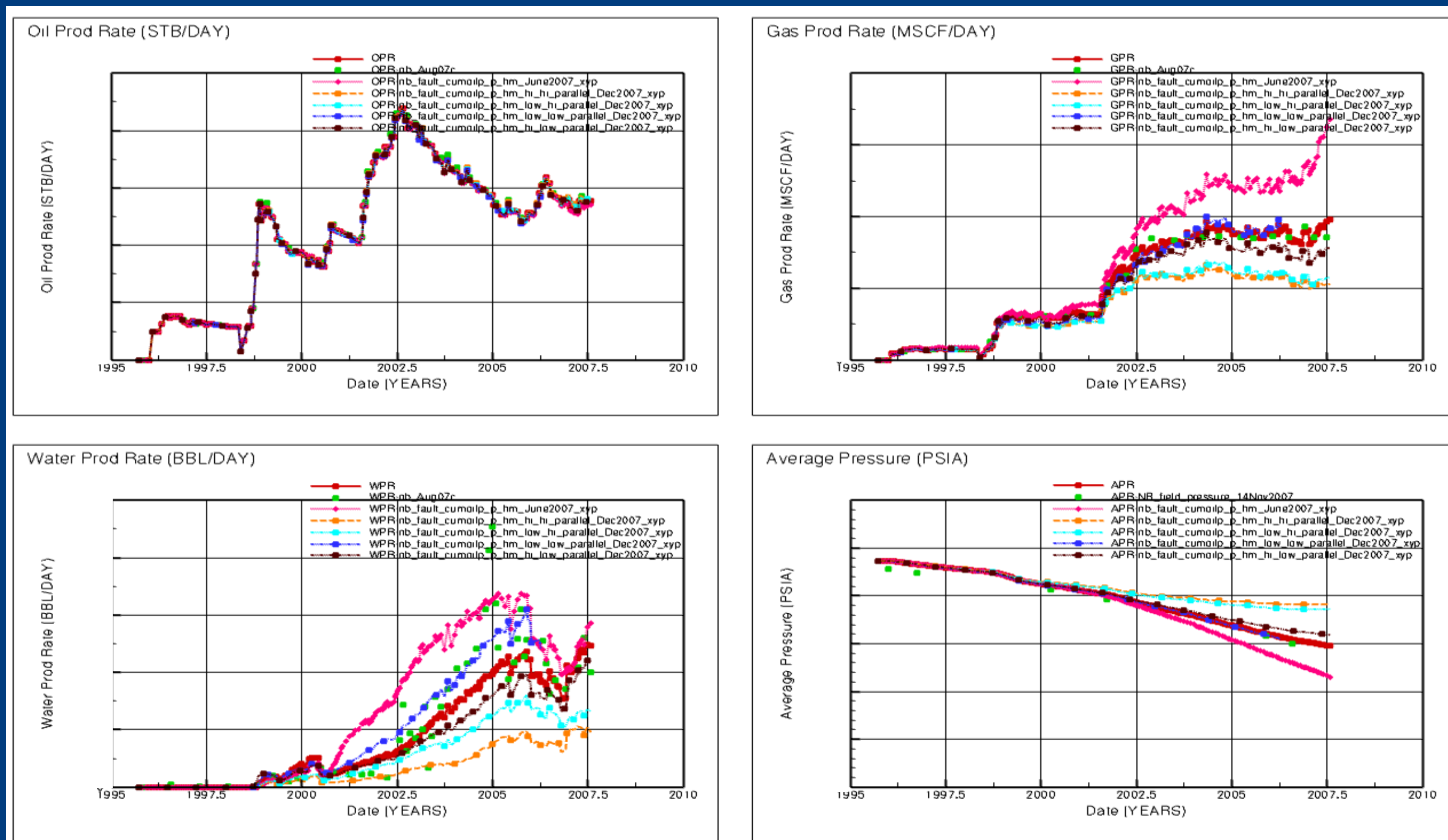
Volumetrics
OOIP and Pore Volume Estimation





OOIP: Original Oil in Place

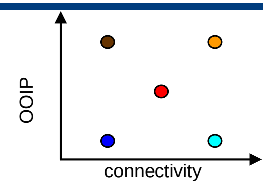
Pre-History Matching Performance of uncertainty scenarios



(1) green dot: observed data

(2) pink line: mid-mid <u>without</u> facies

(3) red line: mid-mid <u>with</u> facies



(4) orange line: high-high (with facies)

(5) cyan line: low-high (with facies)

(6) blue line: low-low (with facies)

(7) maroon line: high-low (with facies)

Results & Conclusion

- Low, Mid and High probabilistic OOIP estimates have been provided for Reservoirs # 1 and 2 using the methodology described in this study. Those estimates express respectively the lowest, most likely and the highest possible oil volumes

- The range between estimated values (low, mid, high) are a direct measure of the degree of uncertainty associated with each reservoir

- Pre History Match reservoir model initialization results are acceptable and they validate the methodology employed in this study

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