PS Using Seismic Facies to Constrain Electrofacies Distribution as an Approach to Reduce Spatial Uncertainties and Improve Reservoir Volume Estimation*

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Abstract

In the 3-D geological modeling workflow, the knowledge of the distribution of facies is a critical step due to the customary non-stationary behavior of the depositional environments, for enhancing a good match between simulation and history matching. Drilling campaigns are looking for areas of interest with better reservoir rock quality, economical hydrocarbon accumulations and help to get in-situ valuable information. This sparse type of recovered information frequently introduces a strong bias in subsequent estimative of facies proportions within the geological grid. Additionally, stationary techniques do not guarantee the appropriate distribution of geobodies, regularly mapped by seismic facies studies.

To overcome the associated uncertainties of the 3-D geological model, we propose a workflow based on the combination of seismic facies and electrofacies. The objective is to constrain the spatial distribution of electrofacies and reduce geological and volumetric uncertainties.

For illustrating such workflow, we use a dataset from a giant field offshore Brazil (Campos Basin). The main challenge is the integration of data from different sources and scales like cores, logs and seismic. Electrofacies are generated from logs (conventional or from images), using statistical methods like multivariate regression or neural network and then extended to the grid scale at well location. A seismic facies classification, based on Neural Network technology, is used for generating a seismic facies volume. The input to the classification process is the result of a simultaneous inversion (Ip and Is) from a set of angle stacks. Neural Network Technology is used rather than any other classification algorithm to better discriminate the lithology and its spatial distribution, keeping the continuity of the facies.

To bring the seismic facies information to the scale of the reservoir grid, a statistical pairing is applied in order to determine the correlation between seismic facies and the electrofacies at well location. The resulting probabilities are propagated throughout the entire reservoir grid, conditioned to the spatial distribution of seismic facies.

Assigning probability of electrofacies occurrence for every seismic facies has proved to be a reliable approach to constrain the distribution of electrofacies on geostatistical algorithms, reducing spatial uncertainties and better estimating volumes of connected geobodies.

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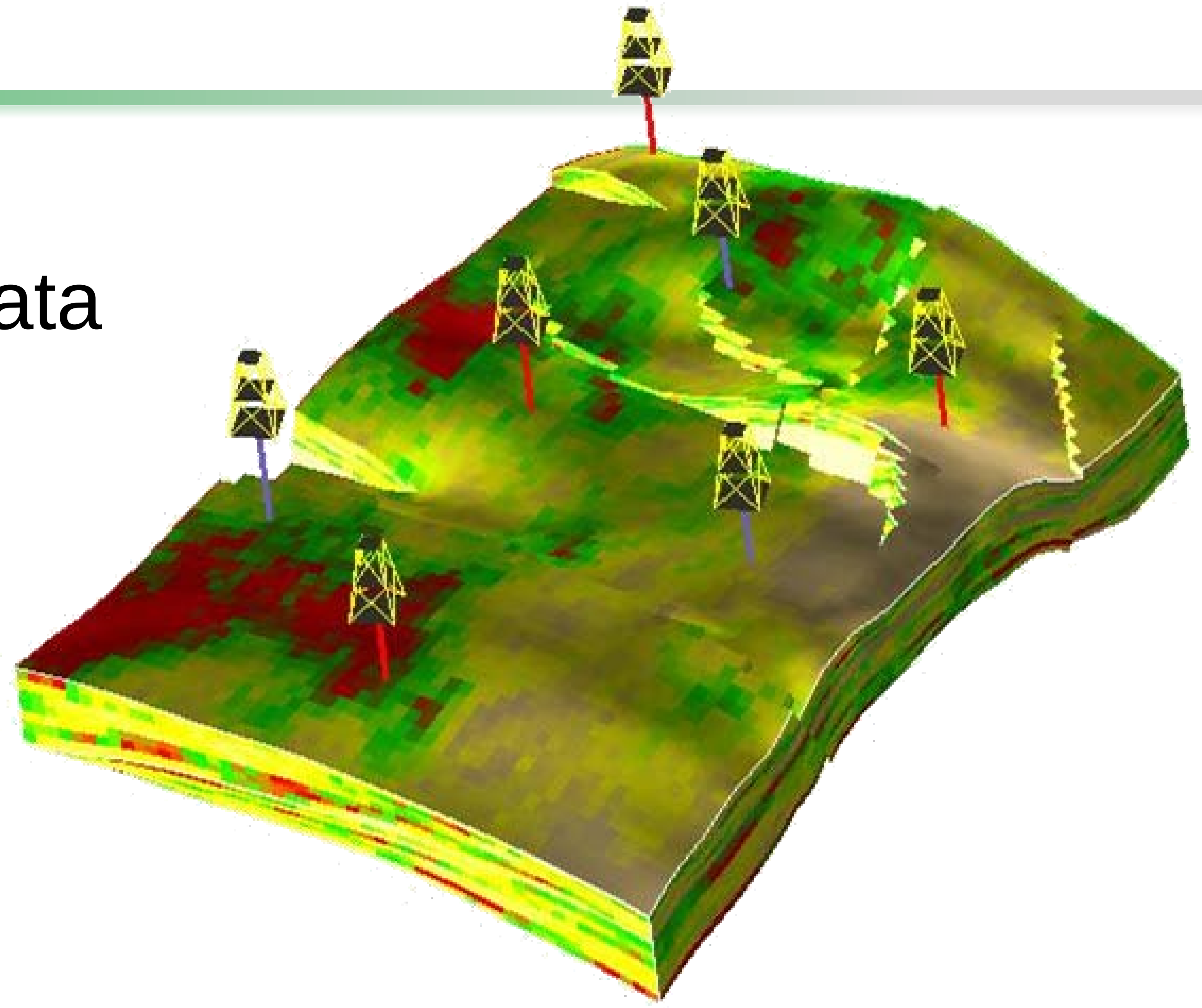
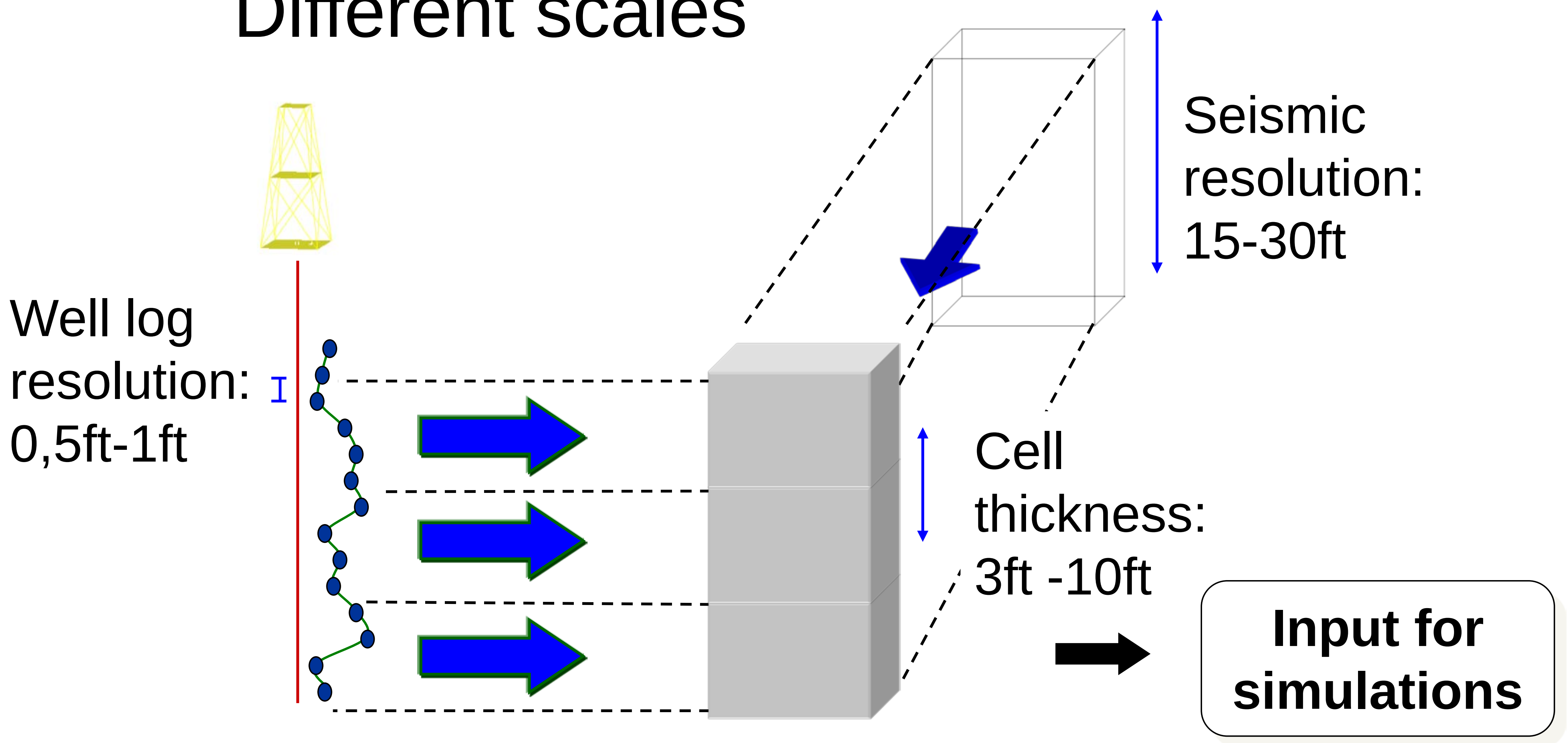
Introduction

- A proper representation of the lithological facies distribution is a critical step in reservoir characterization for an accurate volume estimation, development and production forecast
- Drilling targets are based on definition of areas of interest of better rock quality and accumulations
- The sparse information frequently introduces bias in the estimative of facies proportions
- Stationery techniques do not guarantee the appropriate distribution of geobodies
- Data from different scales available: seismic, well logs, cores

Sparse well data



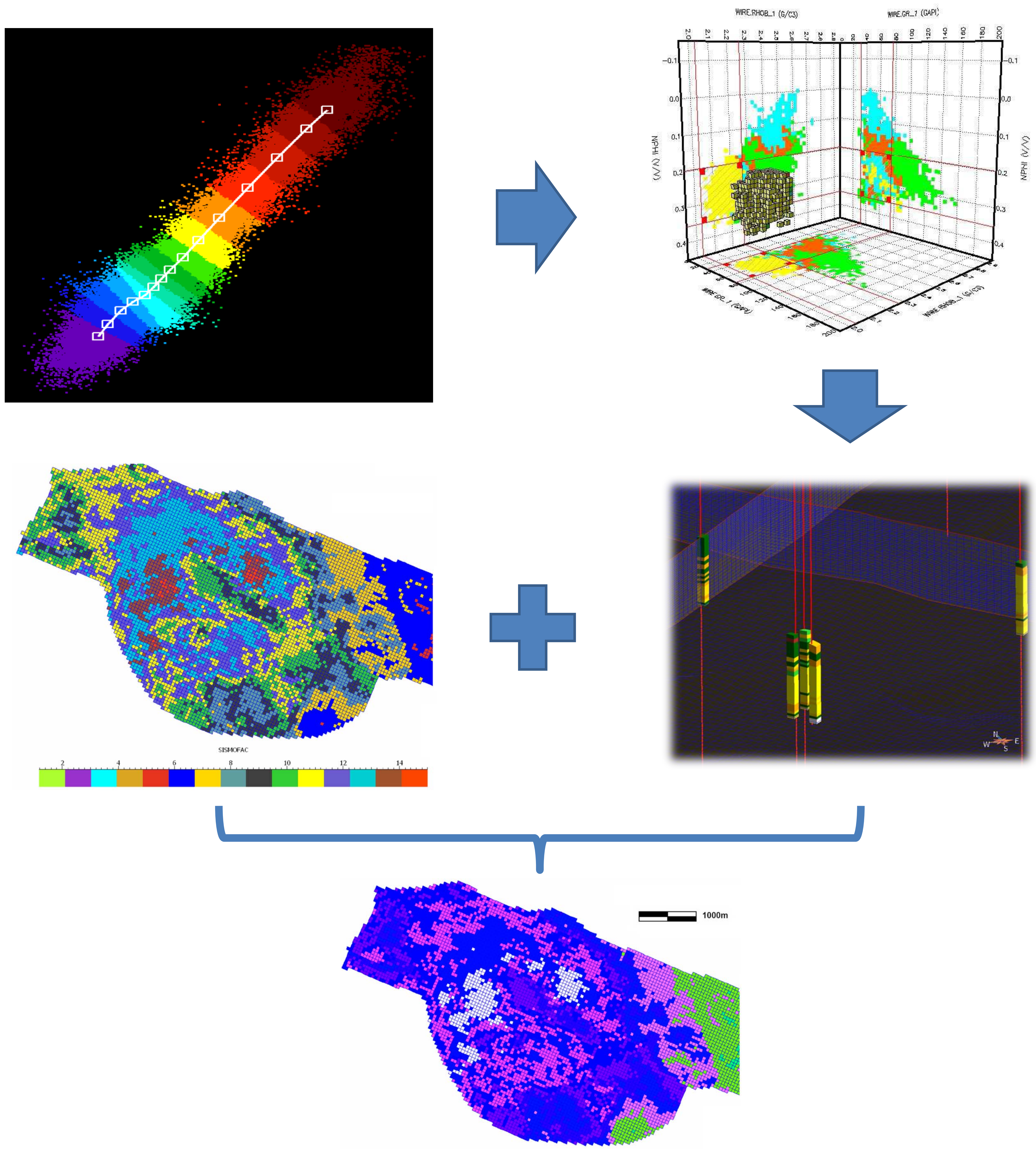
Different scales



Workflow

- Based on the combination of seismic facies and electrofacies to constrain electrofacies distributions applied to a giant field (Campos Basin, offshore Brazil):

- Combine different seismic attributes to estimate the geometry of the depositional environment
- Create electrofacies and upscale them to grid resolution (hard data)
- Create a proportion matrix by pairing statistically the seismic facies and electrofacies
- Simulation
- Post-process resulting simulations for identification of connected bodies.



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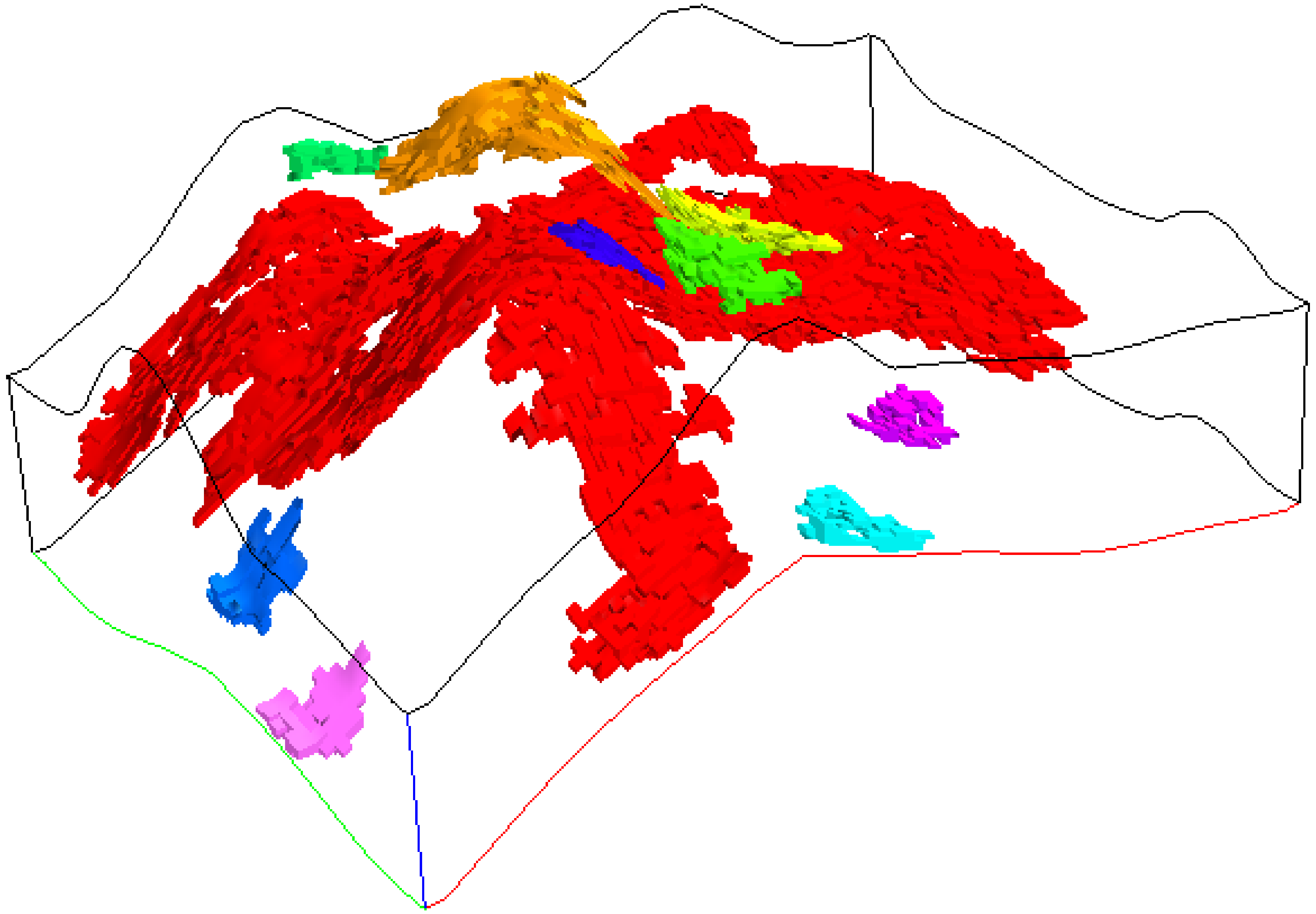
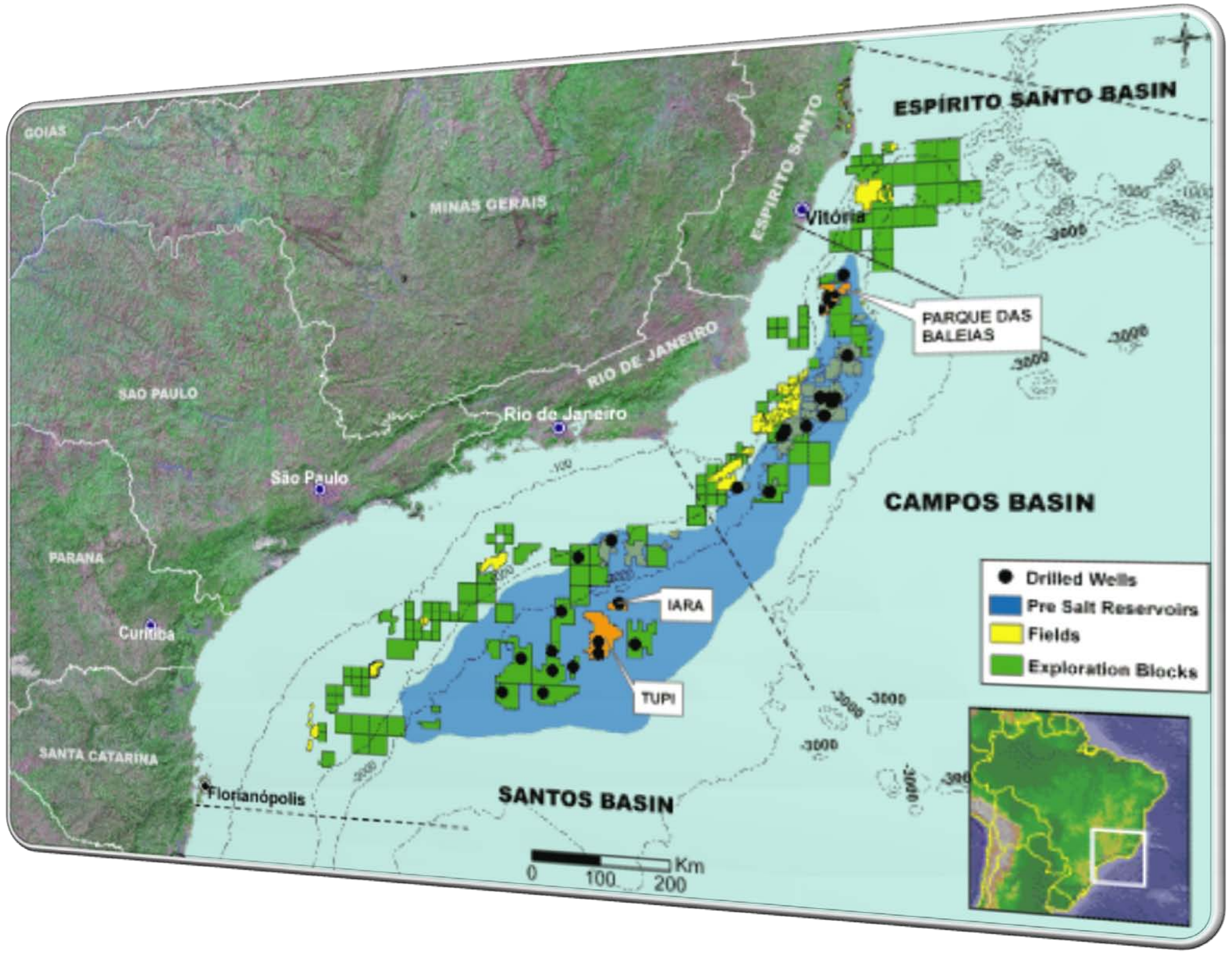


The target field under investigation

- Location: Campos Basin, offshore Brazil
- Discovered in 1975, under production since 1979
- Marine turbidites deposits related to the first important transgression over the Albian limestone shelf
- Channels and lobes combination
- Turbidites trapped in a low
- Accumulation controled both by structure and stratigraphy
- Current production around 3000 m^3 crude/day
- VOIP 110 x 10^6 m^3
- Seismic processing: PSDM, Iterdec, TecVA, Inversion



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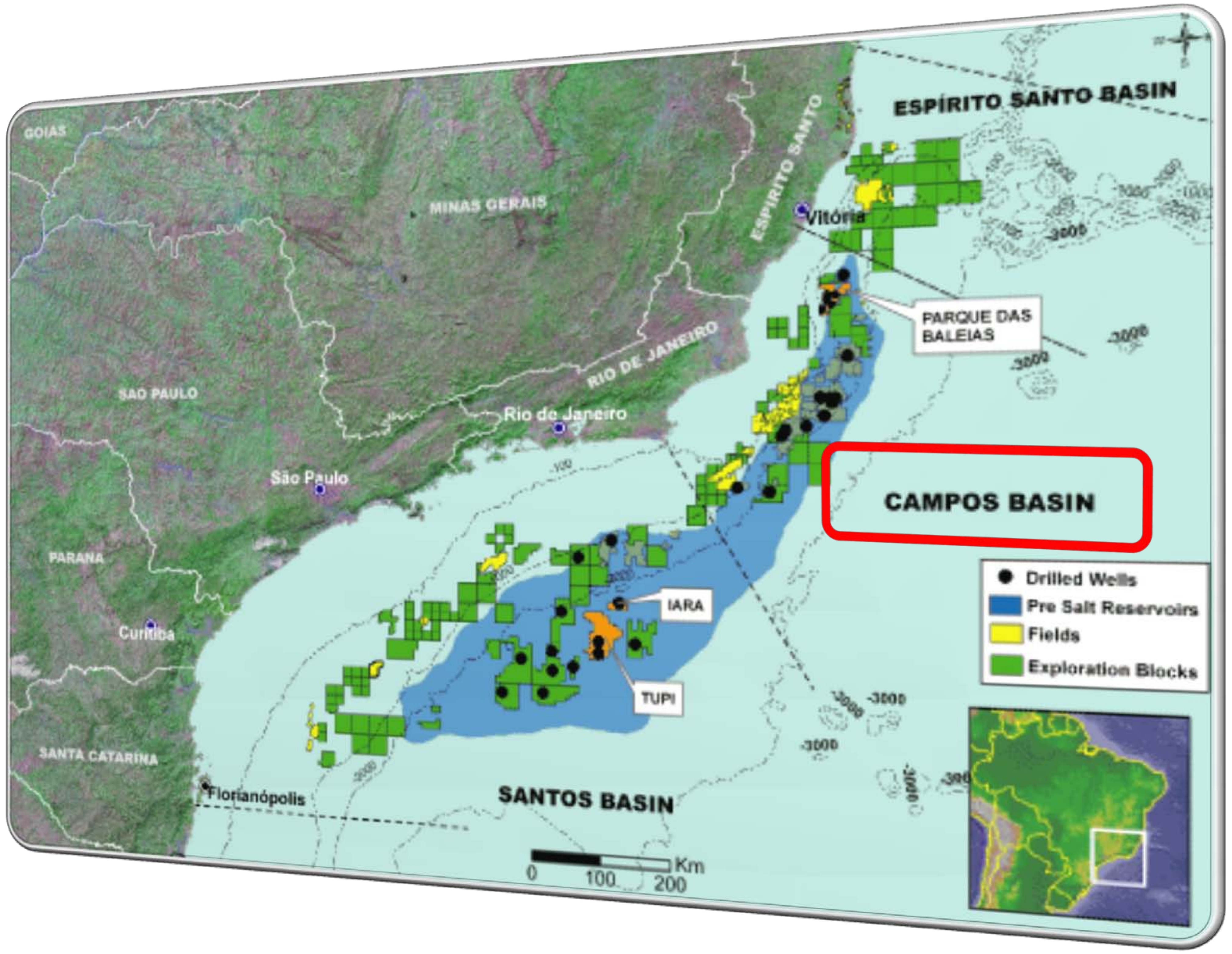
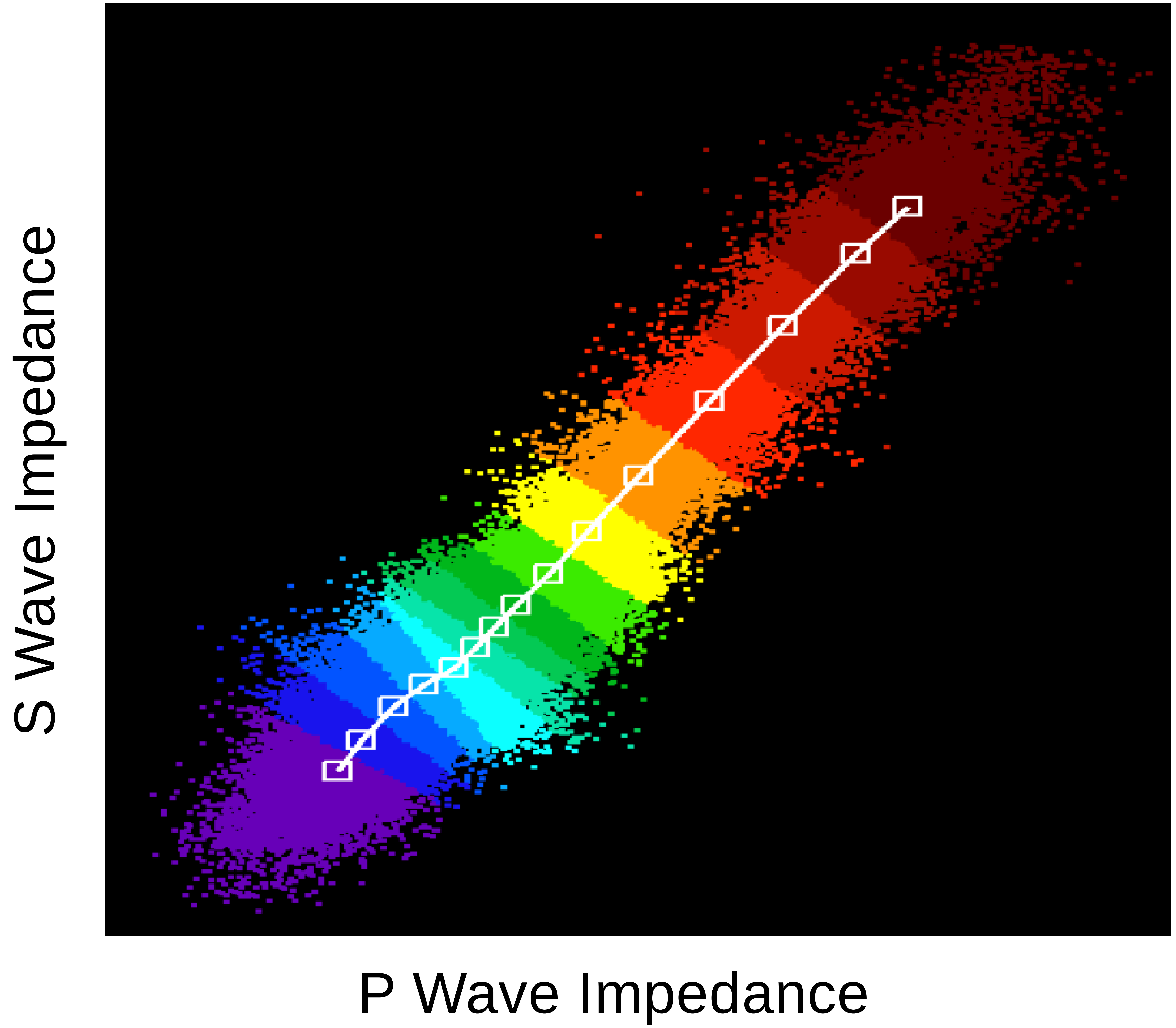


Seismic Facies

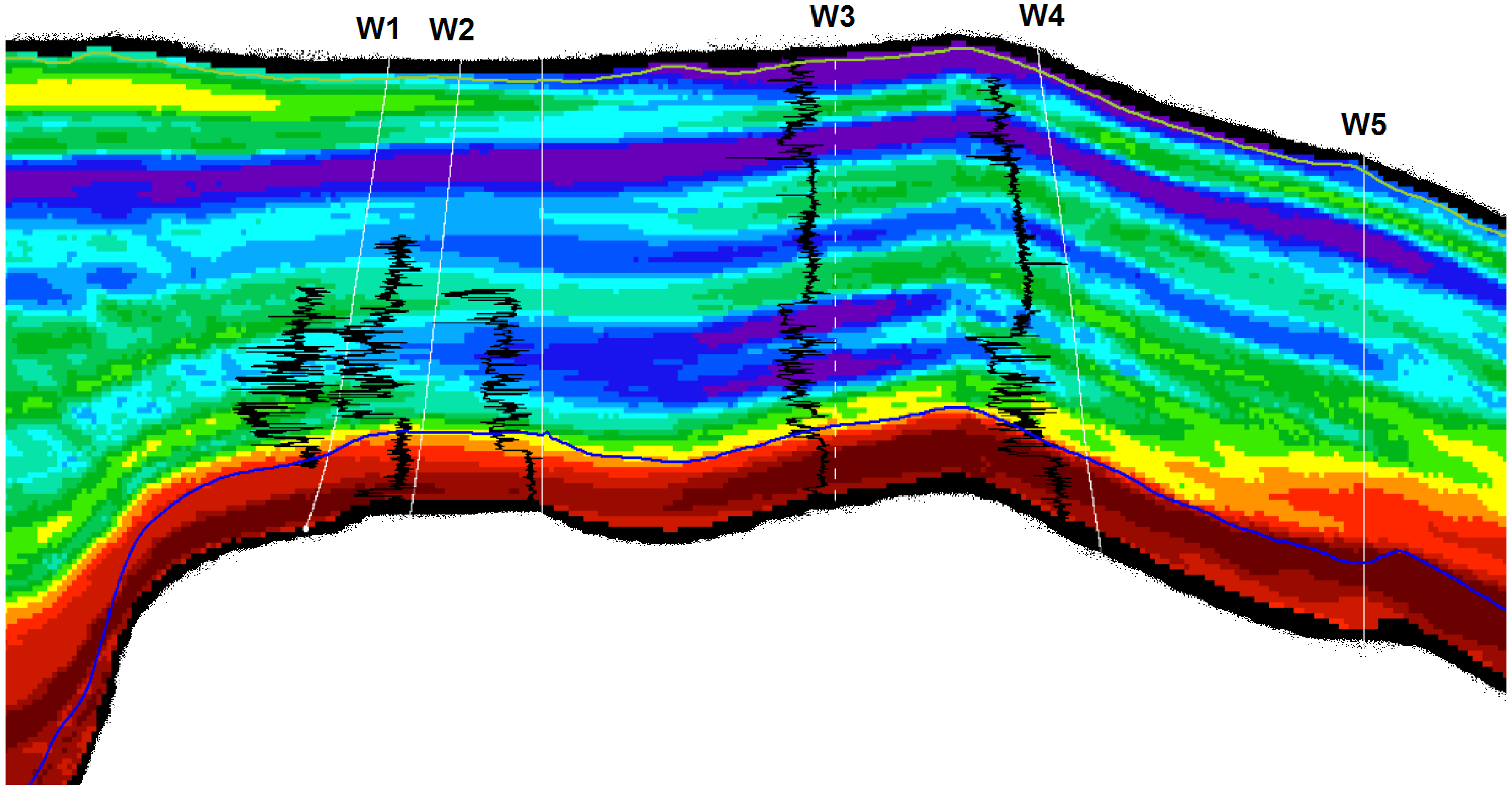
- Seismic Driven Reservoir Characterization workflow:
- Gathers preconditioning, Angle stacks generation
- Pre-stack stratigraphic seismic inversion for obtaining P & S Impedances information
- Neural Network Technology (Self Organizing mapping, SOM) for patterns definition (15 classes)
- Recovering the best model to fit between P & S Impedance to avoid any “away from the background trend“ anomaly
- Best continuity, lateral and vertical distribution and heterogeneity
- Interpretation of the crossplot: Best classes associated to the reservoir (Low Impedance)



Seismic Facies

- Seismic Facies Volume:
- Arbitrary section
- GR along the well path
- Lateral and vertical heterogeneity: this specific behavior would not have been captured by well information only
- Good correlation between GR and seismic facies (W3)
- Best continuity, lateral and vertical distribution and heterogeneities

Arbitrary Cross-Section



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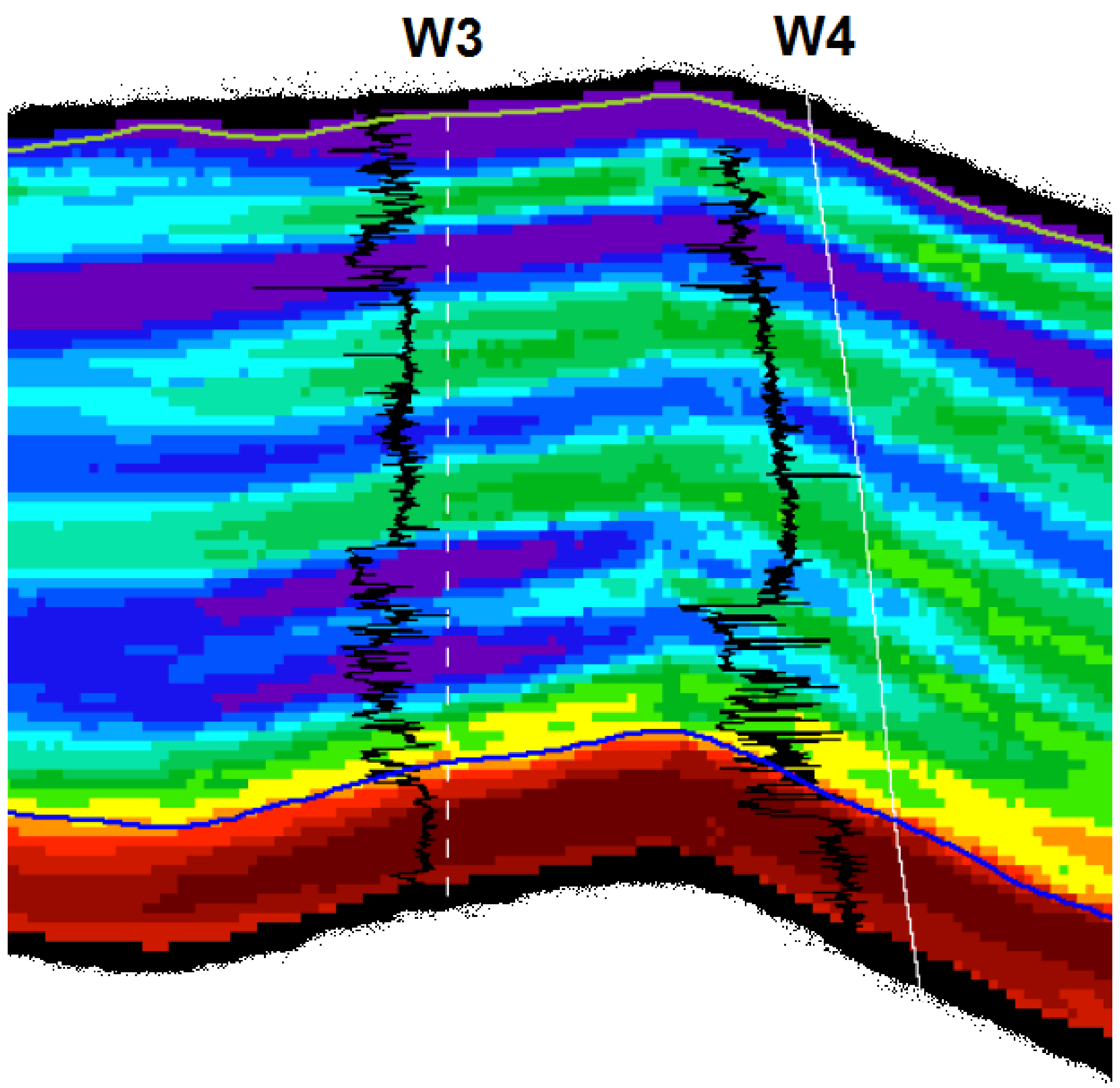
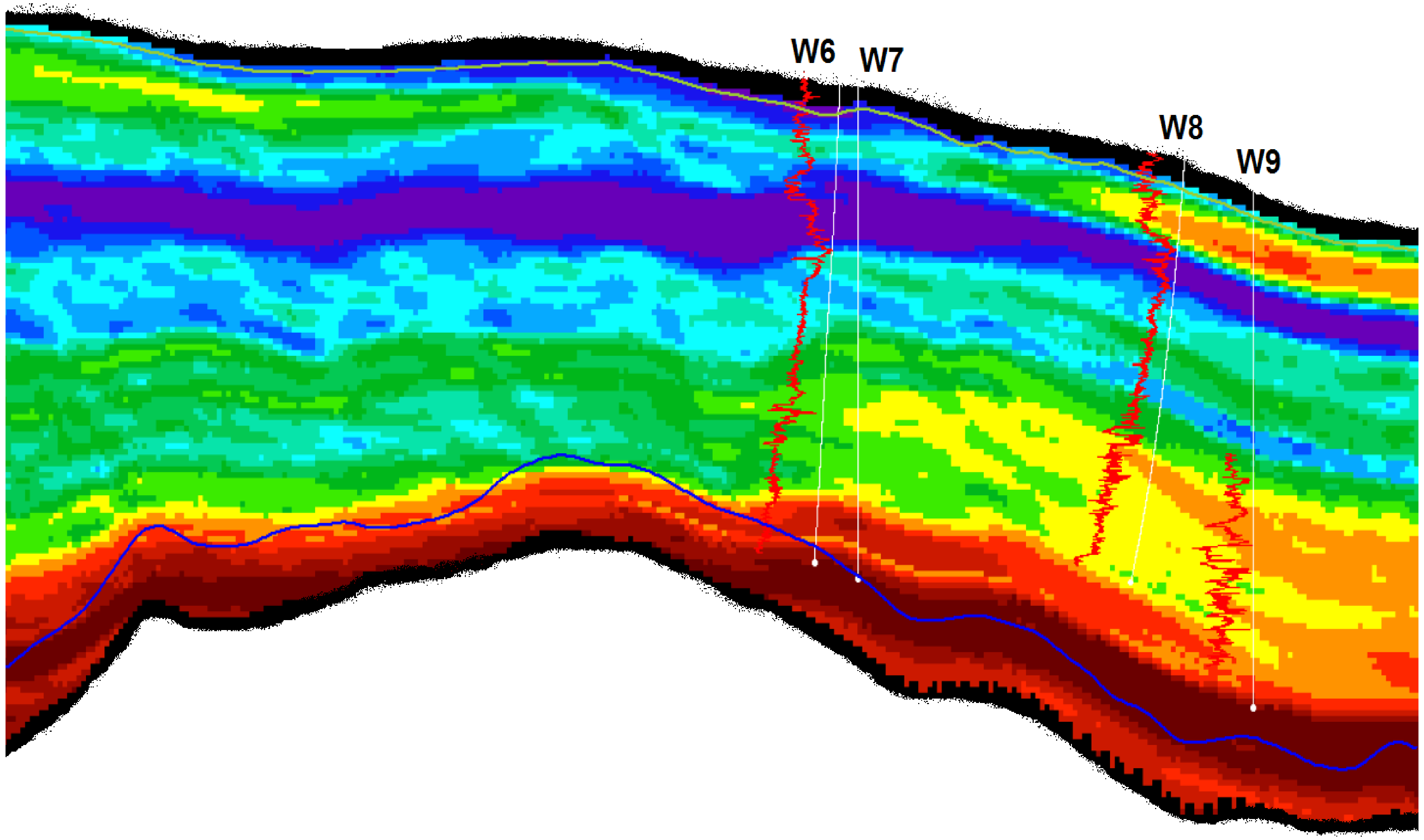


Seismic Facies

- Seismic Facies Volume:
  - Arbitrary section
  - Lateral and vertical heterogeneity clearly highlighted: this specific behavior would not have been captured by well information only
  - The facies associated to the best reservoir quality is showing lateral thickness variations
  - Observe the lower part of the reservoir and the drastic facies variations

Arbitrary Cross-Section

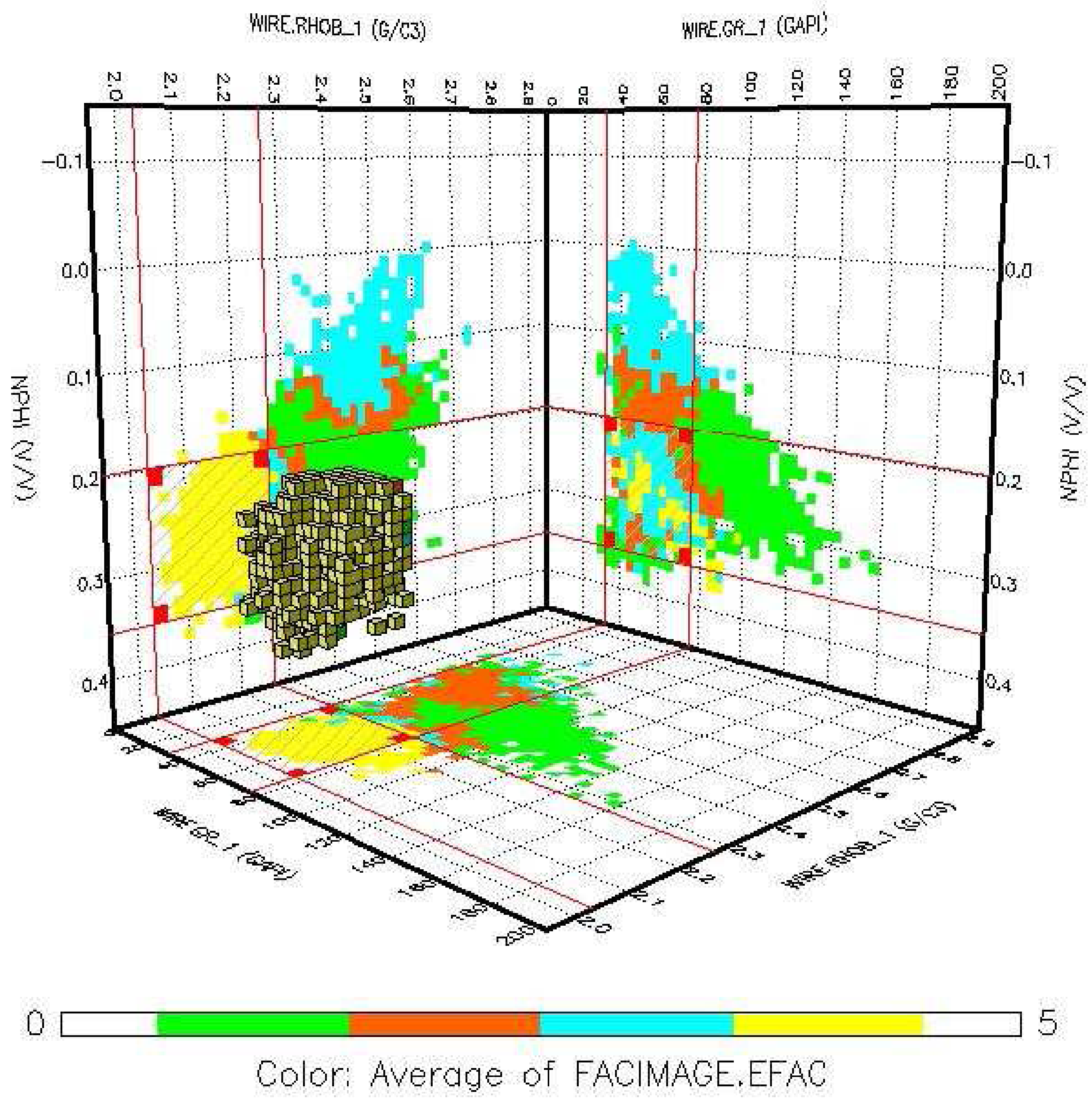


Defining Electrofacies

- Three well logs were used as input for the classification: NPHI, RHOB and GR
- Classification method applied: *Multi-Resolution Graph Based Clustering (MRGC)*
- This method analyzes the underlying data structure to define natural groups of electrofacies
- A priori knowledge of the number of facies is not required
- 4 electrofacies have been defined

NPHI vs. RHOB_1 vs. GR_1

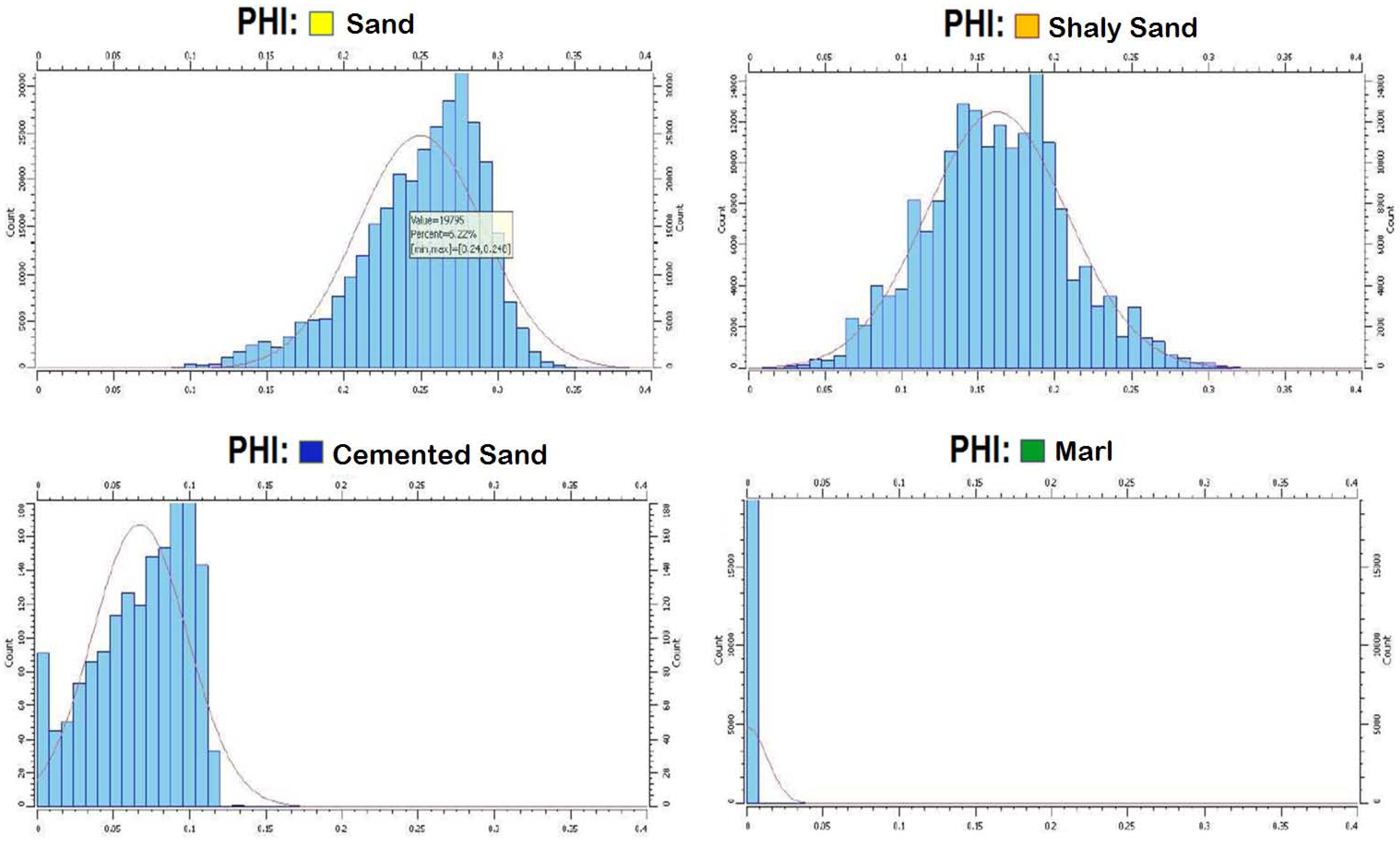
8 wells taken into account



	NAME	COL	PAT	WEIGHT	DT	GR	NPHI	RHOB
1	Facies 4			2708				
2	Facies 2			231				
3	Facies 3			637				
4	Facies 1			2069				

Defining Electrofacies

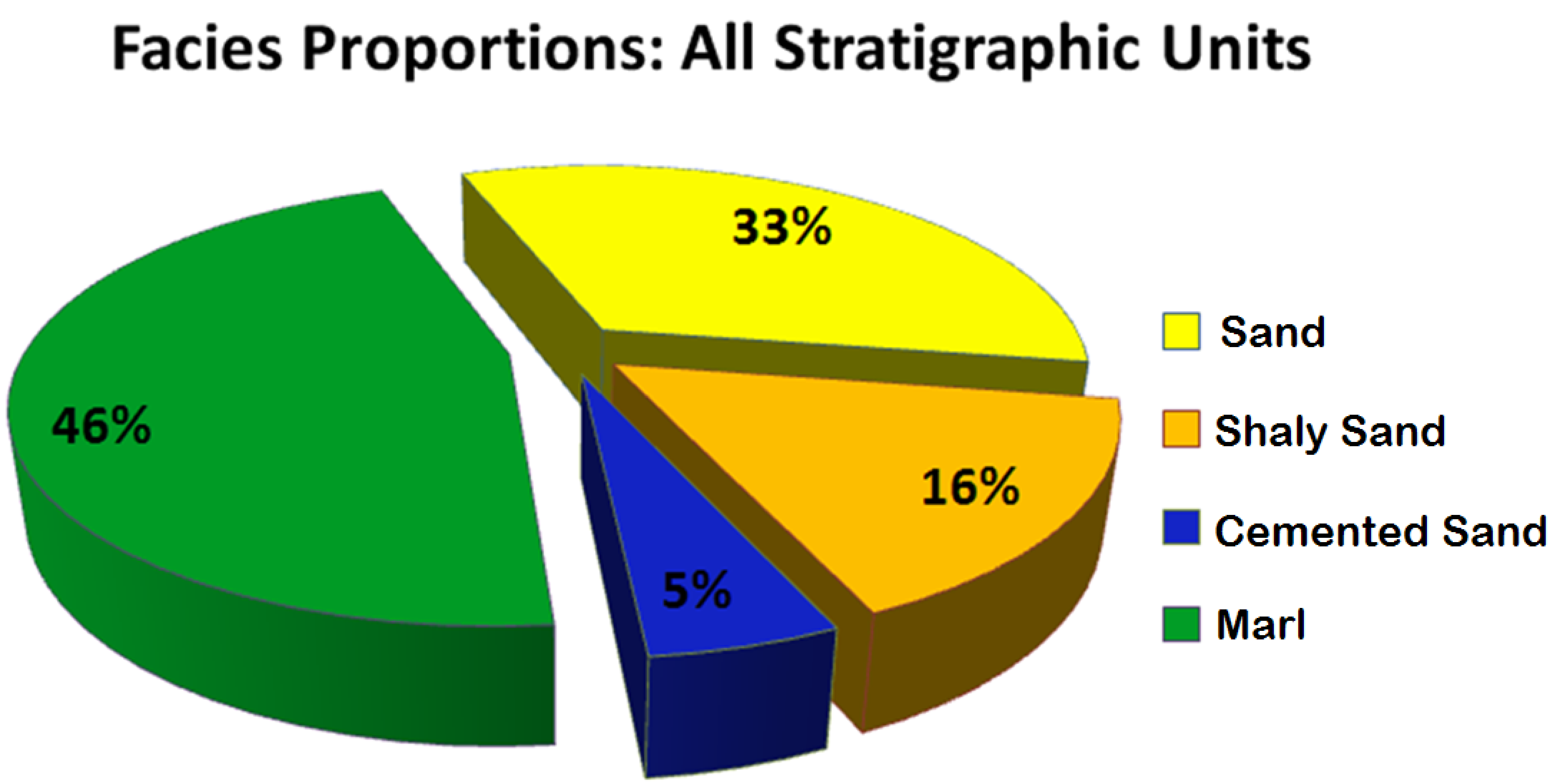
- Histogram showing the porosity distribution for each facies validates the electrofacies classification from the wells
- Distributions for facies Sand and Shaly-Sand will be used as input distribution to populate the respective facies regions in the grid
- For volumetrics purposes, Porosity value = 0 will be assigned to the facies regions 3 (Cemented Sand) and 4 (Marl)

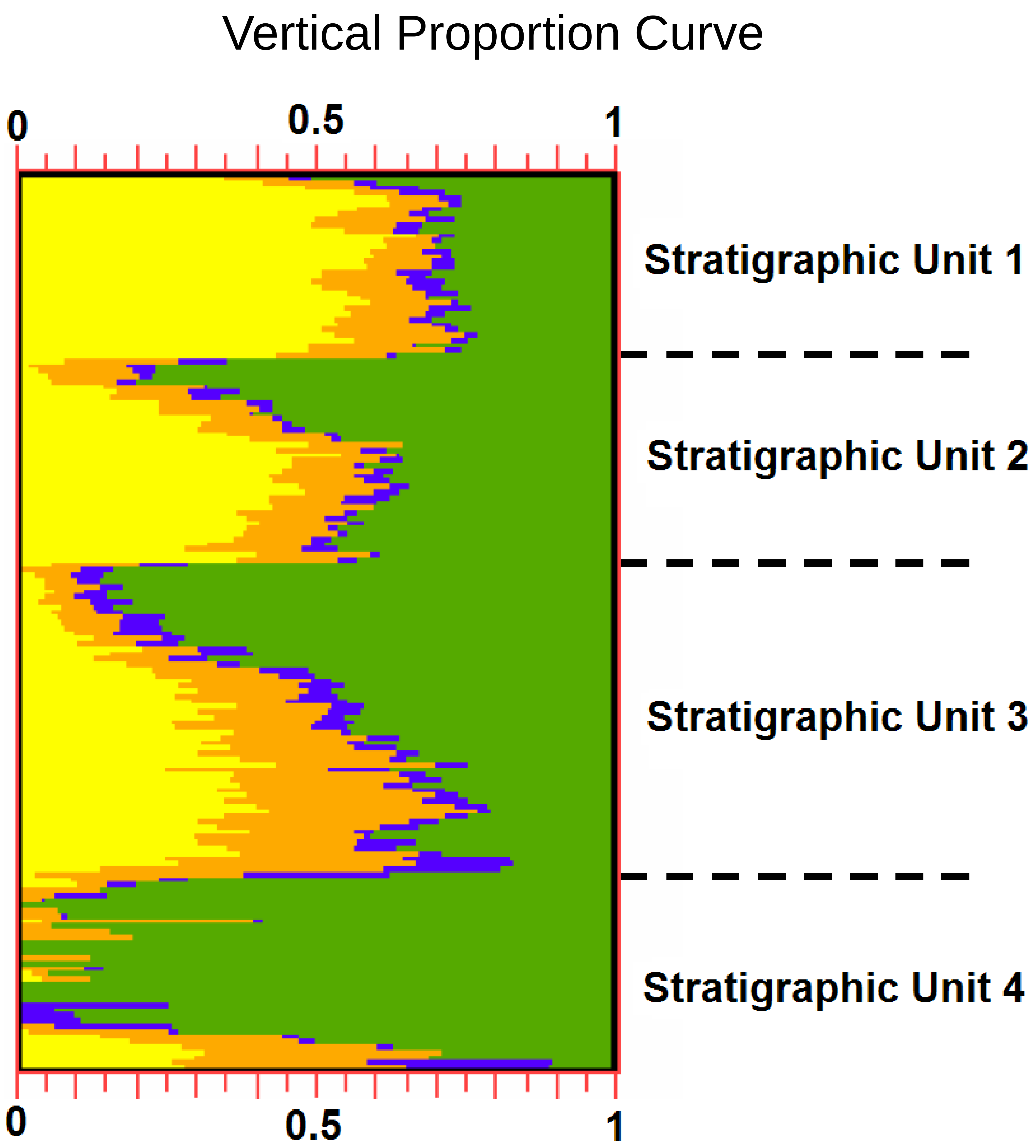


Porosity Distribution per Facies

Defining Electrofacies

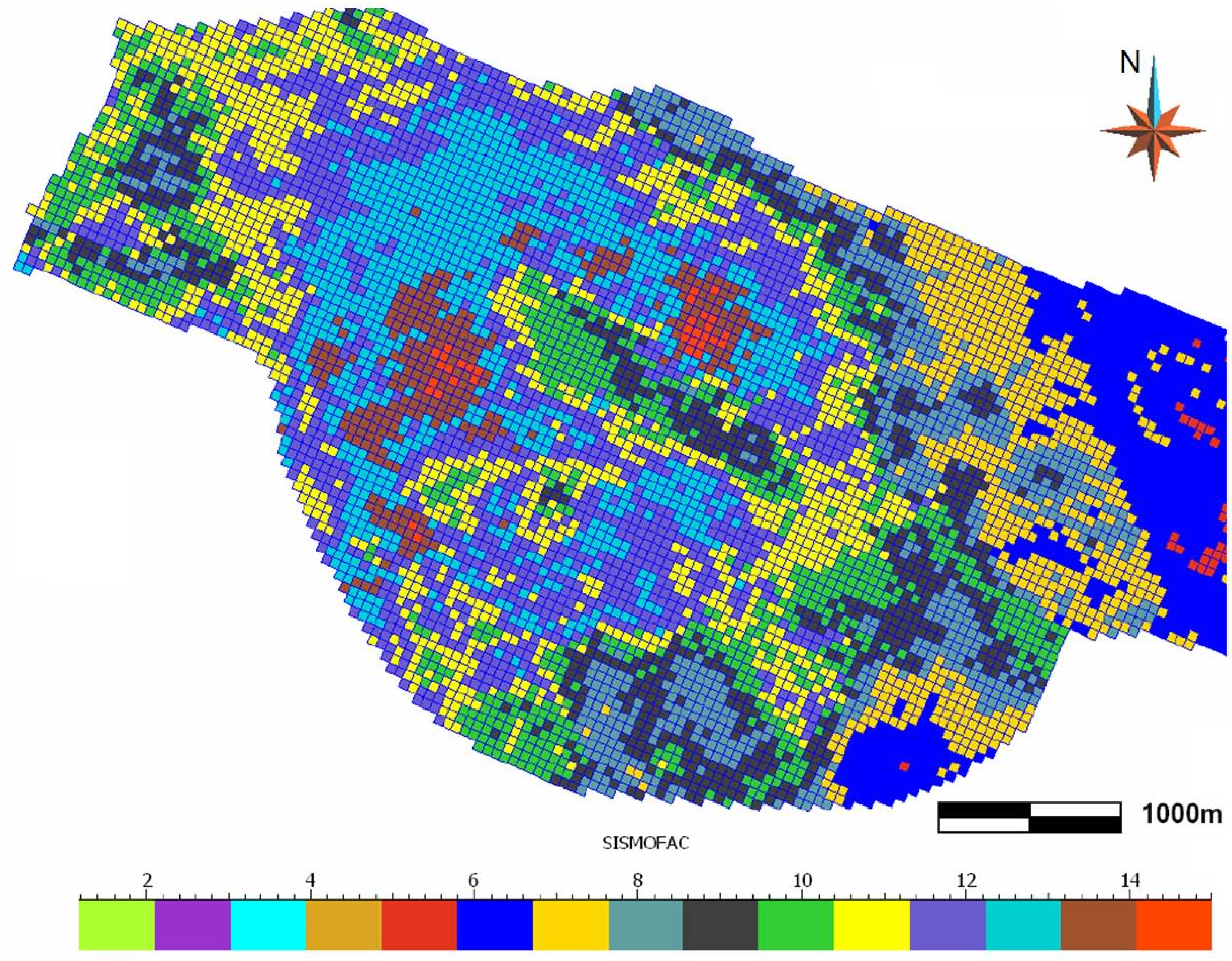
- Based on the sedimentation cycles observed in the vertical proportion curves of facies, 4 stratigraphic units have been defined
- Within each Stratigraphic Unit:
  - Facies 1 and 2: good and regular reservoir quality
  - Facies 3 and 4: non-reservoir



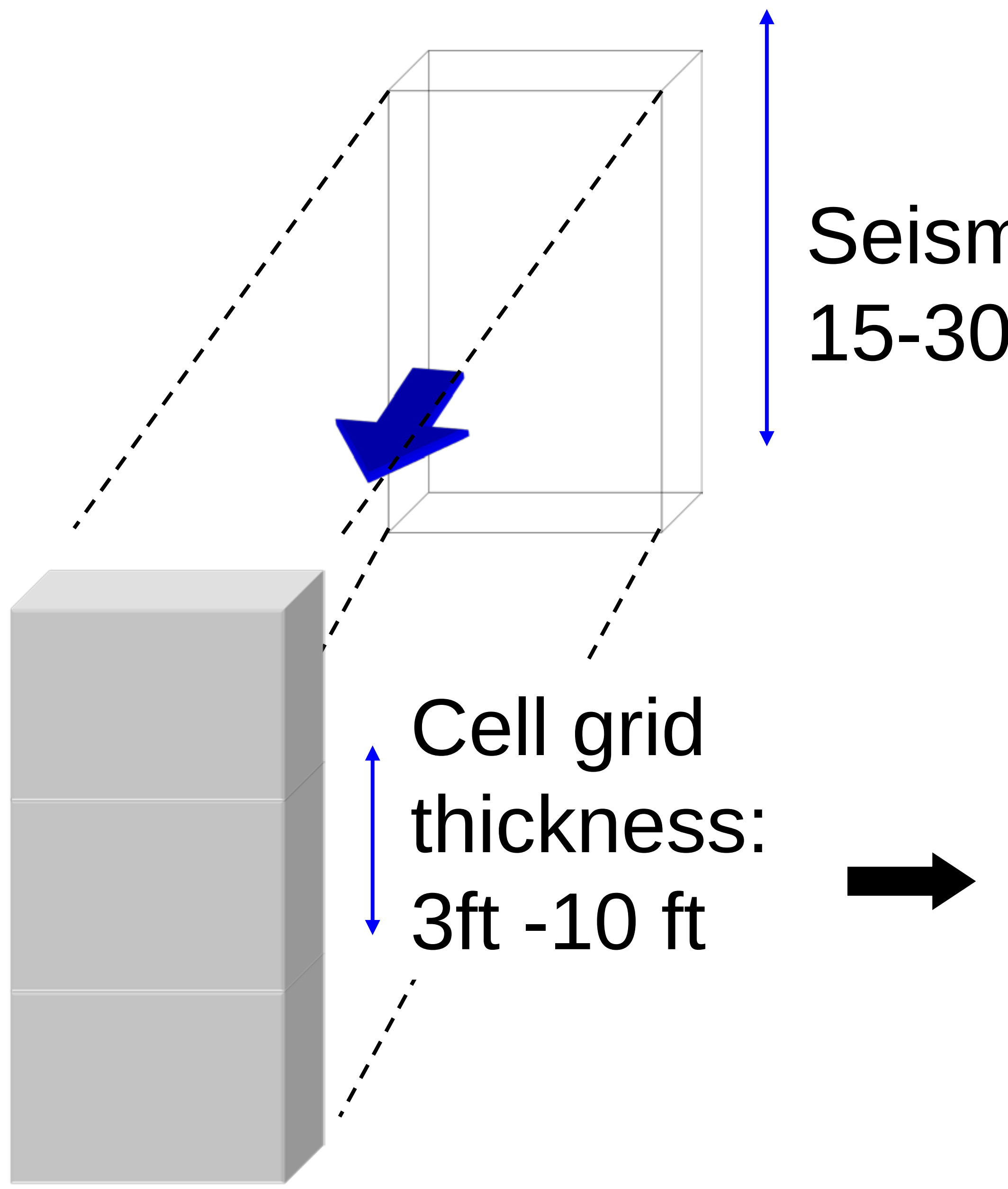


Changing Resolution of the Seismic Facies

Seismic facies on stratigraphic grid (map view)



- Seismic facies are transferred onto stratigraphic grid for further correlation with electrofacies
- The method is based on collocated cells between coarse and fine grids



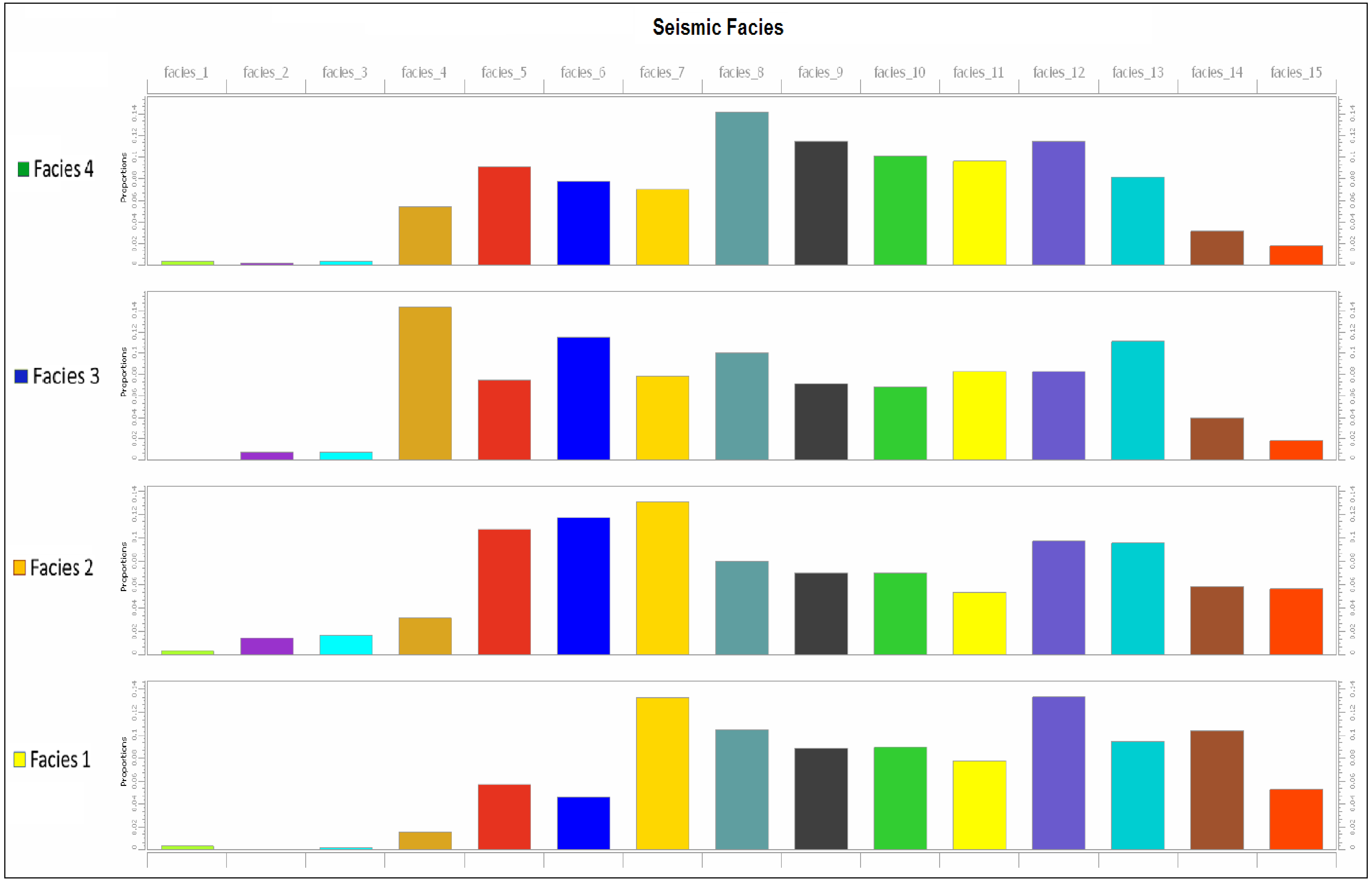
Input for probability matrix

Correlation: Electrofacies vs. Seismic Facies

- At the well location, within the interval of interest, the seismic facies and electrofacies are paired
- From Bayes: Being **n** the electrofacies e_1, e_2 ... e_n and **m** the seismic facies s_1, s_2 … s_n and considering the random variables $E_i = e_i$, i=1…n and $S_j = e_j$, j =1…m :

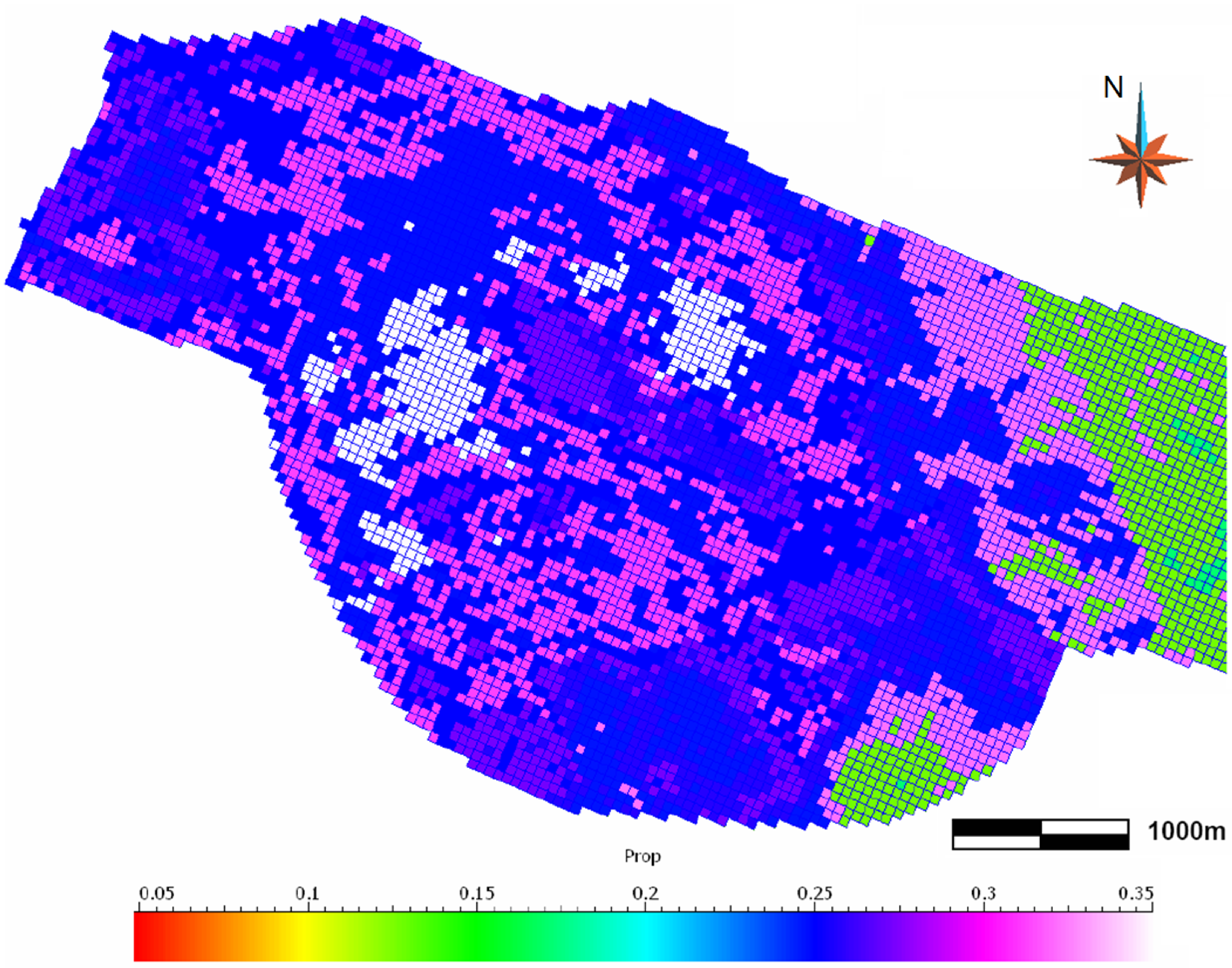
$$P(E_i = e_i \cap S_j = s_j) = \frac{P(S_j = s_j \mid E_i = e_i)}{P(E_i = e_i)}$$

Frequency of seismic facies for each electrofacies



Probability Matrix

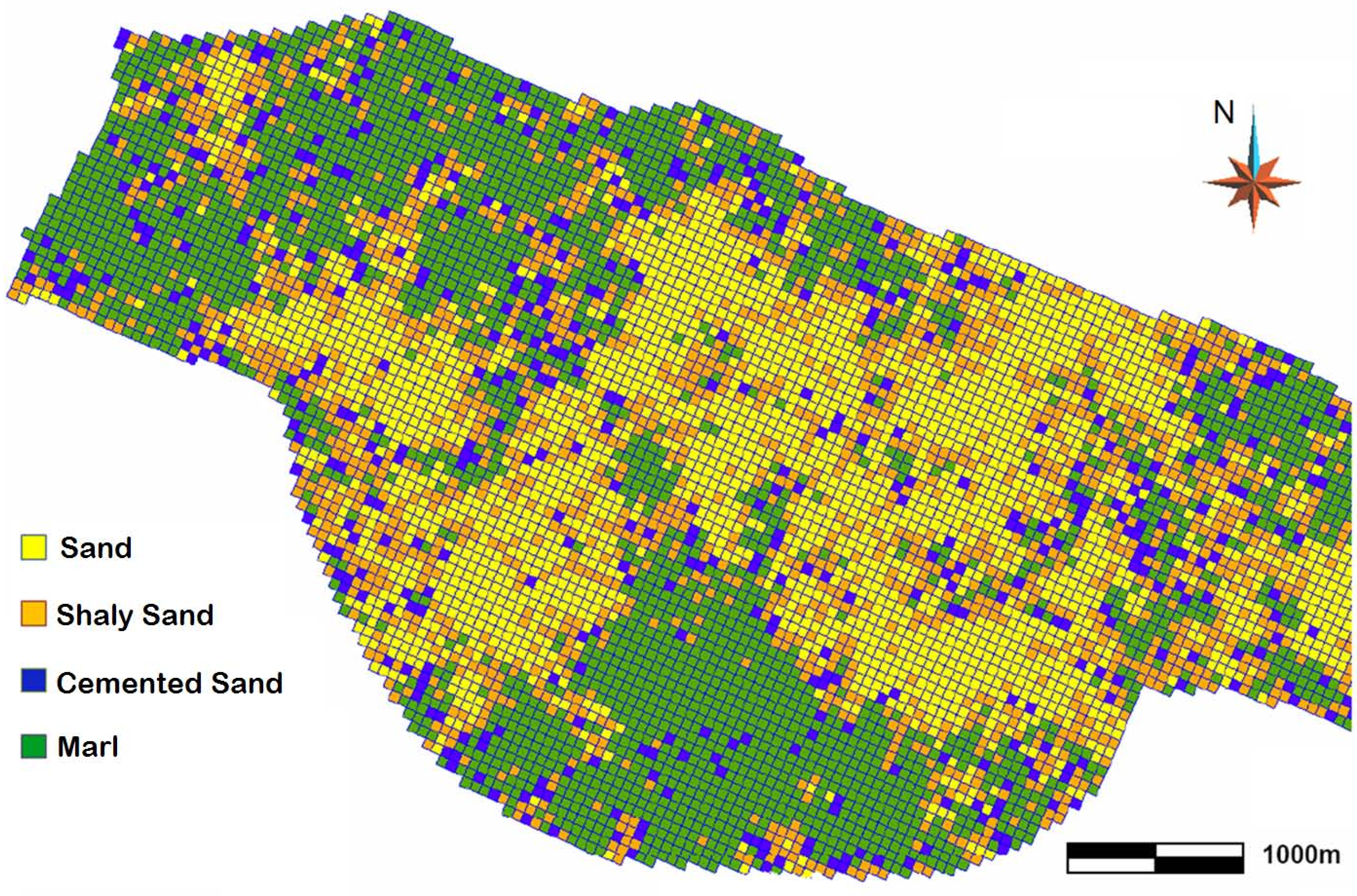
Probabilities for Sand facies (Map View)



- The probabilities found in the wells are propagated to all the cells in the entire fine grid
- At left, stratigraphic section (map) in the grid showing the probability of ocurrency for electrofacies 1 at each cell location
- Each cell brings 4 elements, being each element the probability of occurence for the respective electrofacies
- Probability values will be used to constrain the electrofacies distribution in the stratigraphic grid

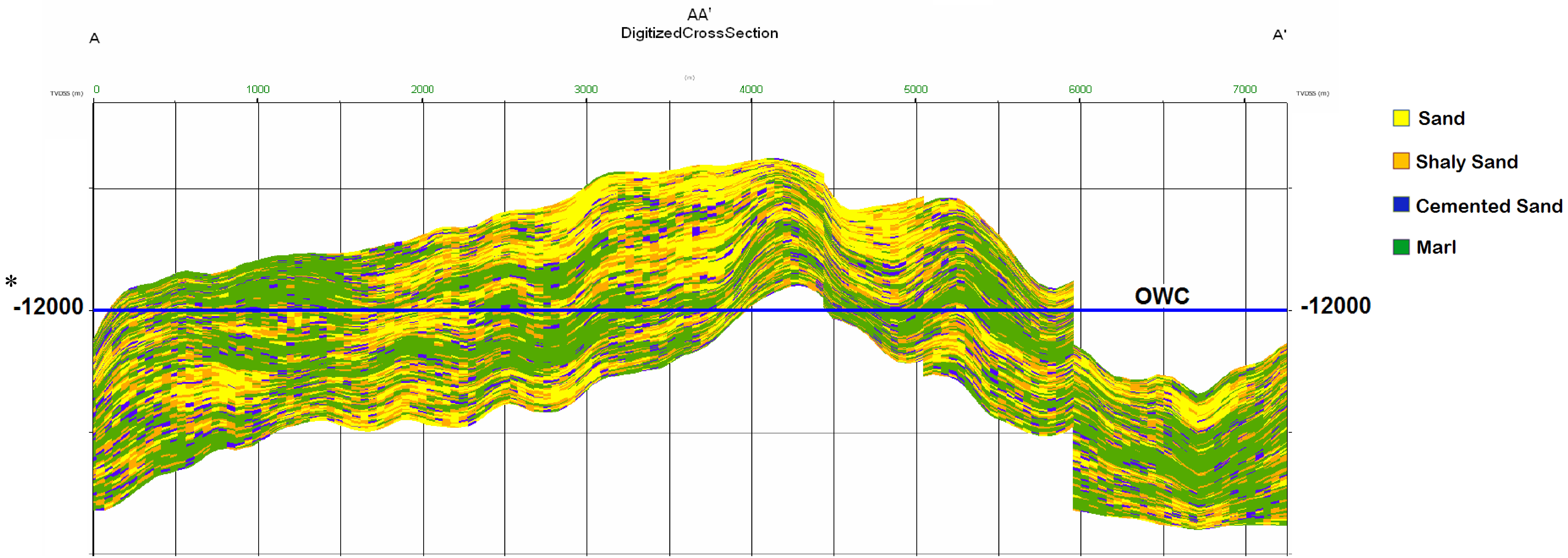
Electrofacies Simulations

Facies simulation constrained by 3D probability cube
(Map View)



- Truncated Gaussian Simulation has been used for representing the observed sequence of facies
- In this first phase, 30 realizations were performed
- 3D probability matrix was used as a secondary data to constrain the electrofacies distribution
- Non-stationary model due to the influence of the seismic facies (areal and vertical control)

Electrofacies Simulations



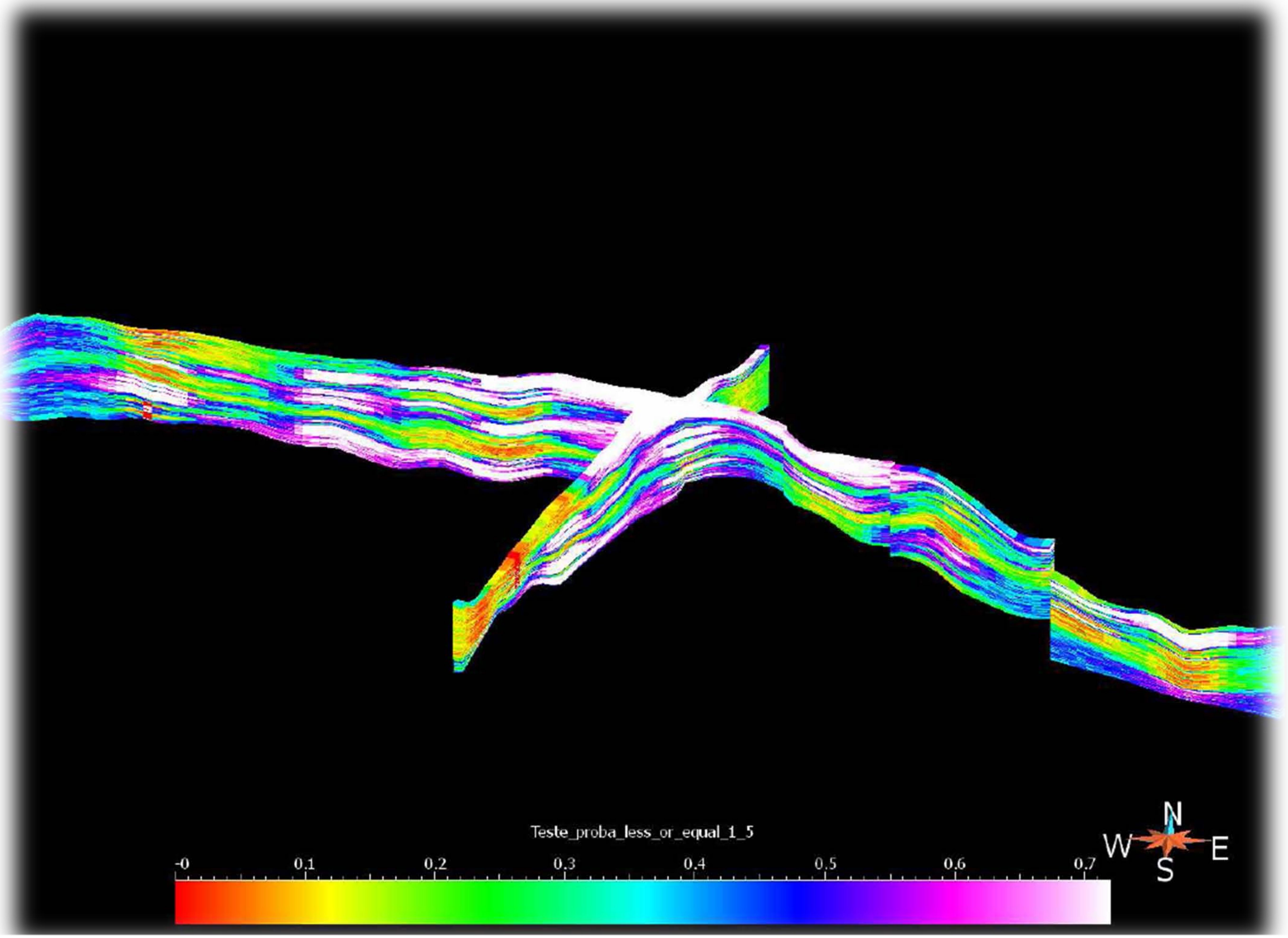
- Arbitrary cross section shows the distribution of facies for one of the 30 realizations
- Geometries and reliable positioning of the lithological elements constrained by seismic attributes improves reliability on net pay and volumetrics calculations

* *Due to confidentiality reasons, OWC depth does not reflect the true depth*

Simulation Post-Processing

- All the facies realizations were post-processed to generate 3D probabilities in order to identify regions with better rock quality
- A connectivity analysis was performed to identify connected bodies for the net region
- Results clearly identify the potentially targets
- Ranking realizations by VOIPP taking into account connected bodies hit by producers wells is part of the next investigation phase

Simulation post processing: probabilities of having facies 1 or 2



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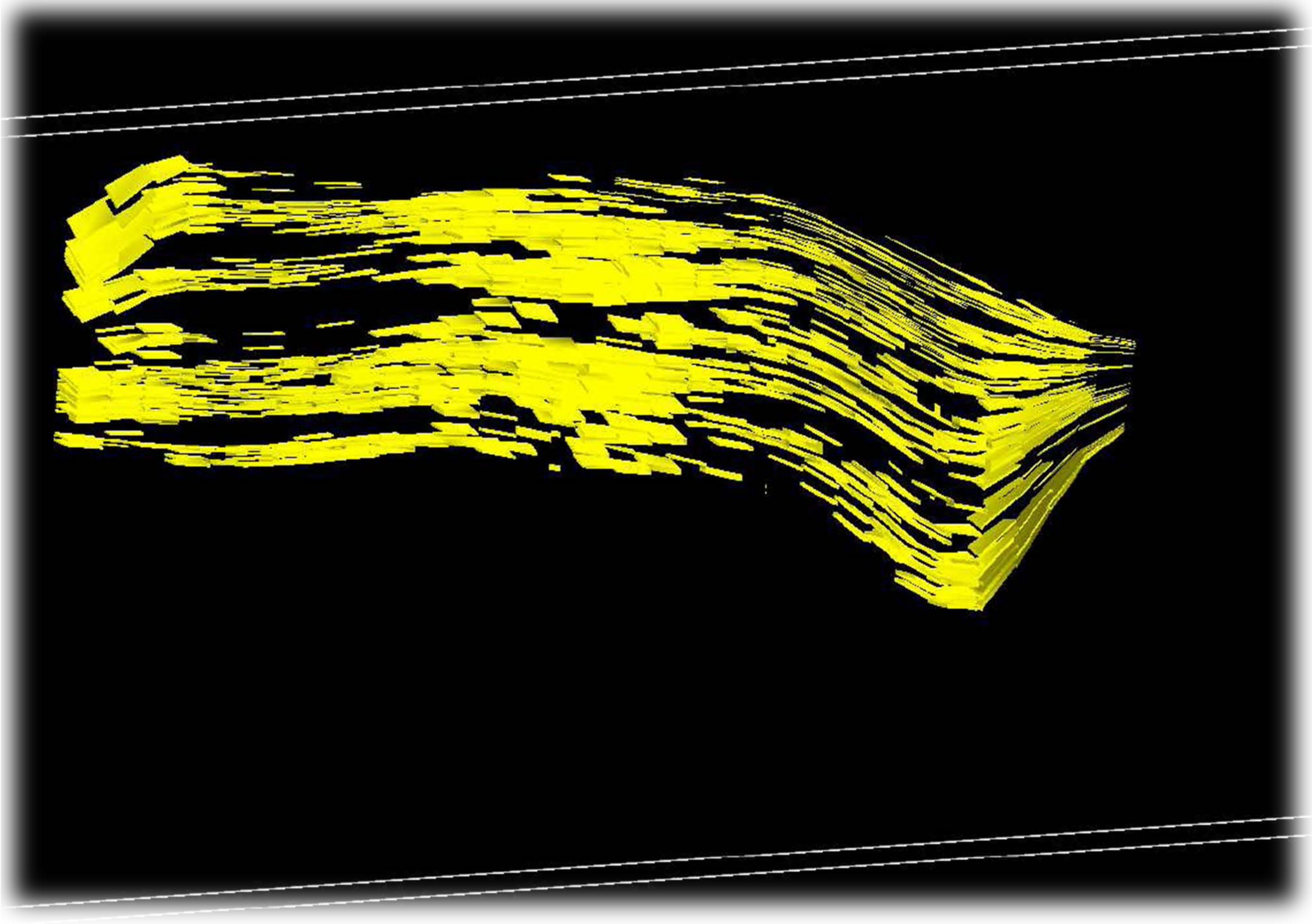
Analysis of connected bodies for facies 1 or 2



Conclusions

- Data integration is the right path to extend a very local information (hard data = well information)

- Reservoir Modeling Technologies are proving to be the effective approach to merge data of different scales

- Reducing uncertainties on lithofacies positioning

- Identification of the geomorphology of the geobodies constrained by seismic attributes improves reliability on net pay and volumetrics calculations