Probabilistic Reservoir Characterization via Seismic Elastic Inversion in East Andaman Basin*

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Abstract

East Andaman Basin is a frontier area located at the south-eastern corner of Indian Territory in the Andaman Sea. It's bounded by the volcanic Mount Sewell Rise on the West, and the continental Mergui Ridge on the East (Figure 1).

Recent 2-D and 3-D seismic surveys results indicate that the basin has accommodated a thick pile of sediments through Cenozoic.

The area chosen for the study is in the exploration stage, and no well has been drilled so far; so the data of five wells from an analogue basin were the only suitable to define a lithological setting via electrofacies logs.

A seismic (elastic) inversion of East Andaman Basin 3-D volume led to the production of Acoustic Impedance and Poisson's ratio cubes. The calibration of those elastic properties volumes was carried out by using electrofacies logs, considering the same a-priori information coming out from the analogue basin wells.

Due to possible differences in burial history between the Andaman and the analogue basins, differences in Seismic Velocity and Density trends had to be managed during seismic inversion and lithology calibration. The final solution accounted for a de-trending, by generating "relative" elastic attributes which were used to define the electrofacies classification and a lithological volume in the area of interest, for seismic-reservoir characterization purposes.

The litho-classification solution was not deterministic but stochastic, allowing the computation of additional lithology probability volumes.

Scope of Work

The aim of the work consisted of generating a lithological volume starting from the integration of wells and seismic data. A number of approaches can be found in literature to the purpose, but the peculiarity of the area of interest consisted of an absolute lack of wells. Therefore some workaround had to be found in order to make profitable use of well data available from an analogue neighbouring basin.

Below are the main steps followed during the process:

- Selection of well data from analogue basin (North Sumatra Basin)
- Electrofacies Analysis on well data
- Lithofacies Classification and grouping from Electrofacies
- Seismic Elastic Inversion of 3-D volume of East Andaman Basin
- Lithological calibration of Inversion output volumes
- Probabilistic Lithological Model
- Depth Conversion of Litho-volumes

Well Selection, Data Q.C., and Electrofacies Analysis

Appropriate wells were selected within an analogue basin (North Sumatra Basin), on the base of: acoustic and elastic logs availability, stratigraphical consideration about the presence of a suitable drilled and logged section covering the similar targets of the area of interest. The building of an electrofacies model had to take into account the main lithological characters of the syn-rift and post-rift Oligo-Miocene succession. All the available logs were considered, taking into special account Sonic and Density Logs were used for the acoustic impedance computation.

The electrofacies were defined using an automatic cluster analysis algorithm. Key Nearest Neighbour was used to define the electrofacies model. This approach requires the use of a training set involving reliable values of the log to be reconstructed (dependent variable) and some related logs (independent variables) as a reference. The dependent variable is predicted for another data set ("query" set), based on the comparison between the values of the independent variables in the training set and in the query set (Figure 2).

The following logs were used for the electrofacies definition:

- GR (Gamma ray)
- DT (Sonic P-wave)

- NPHI (Neutron porosity)
- RHOB (Bulk density)

The additional estimator DNDIF (density-neutron separation at the limestone scale) was considered to improve the classification. This parameter was calculated as follows:

$$DNDIF = RHOB - [2.71 - (NPHI / 0.60)]$$

It is practically independent from porosity and takes the same values for samples having the same lithology and/or clay fraction, so it commonly represents a good shale descriptor.

The clusters were manually merged to obtain homogeneous lithological and petrophysical classes. The final result includes 12 facies (Figure 3).

The crossplot of different petrophysical logs were performed and electrofacies characterization was defined (Figure 4a and Figure 4b).

Lightfaces Classification

It was observed that the electrofacies could be combined, taking into particular account the Sonic and Density data, into four major lithological groups. The following grouping was assumed (Figure 5) and subsequently used for seismic classification purposes.

- Carbonates (facies 1-3)
- Sand/Sandstone (facies 4-6)
- Silt/Siltstone (facies 7-9)
- Shales (facies 10-12)

The following composite represents an example of the discrete facies log vs acoustic impedance log (right track in Figure 6).

Seismic Elastic Inversion and Probabilistic Lithological Model Building

The preparatory works for elastic inversion were comprehensive of building an a priori (initial) low-frequency model.

Using Dix equation, constrained by the available interpreted seismic horizons, an interval velocity cube was computed from the seismic (stacking) velocity. The Rhob a priori volume was computed by using the Gardner equation generated by Density-Sonic log relationship from the available wells (Figure 7). The Shear velocity (Vs) initial cube was also generated from Compressional velocity

(Vp), considering a Vp-Vs empirical relationship based on the available logs.

Poisson's Ratio initial model was consequently generated on the above mentioned basis.

The seismic elastic inversion was carried out on the 3-D seismic data volumes (Near and Far partial angle stack) of the Andaman area, in order to generate Elastic parameters (see a representative extracted wavelet in Figure 8).
It was found convenient to work on the Acoustic Impedance vs Poisson's ratio domain. Therefore these typical inversion-output parameters are here considered as the reference ones for litho-classification purposes.

PetroElastic analyses from well data confirmed that the Acoustic Impedance vs Poisson's Ratio domain is suitable for the relevant lithofacies discrimination (Figure 9).

The Acoustic Impedance-Poisson's ratio classification model is based on well data pertaining to a different basin; the absolute values are strictly dependent on the Seismic Velocity and Density trends.

The trends revealed by well data analysis were compared with the ones foreseen by seismic data in the area of interest. The difference between the AI vs PR trends on well data and seismic data suggest a possibility that in the two distinct areas different sediment compaction histories can be recognised.

Relative Acoustic Impedance and Relative Poisson's ratio were therefore computed by de-trending the original data in order to make PetroElastics independent from trends of wells and seismic inversion-derived datasets (the latter in Figure 10 and Figure 11).

Lithofacies discrimination exercise based on the available well data was repeated on Relative Acoustic Impedance vs Relative Poisson's ratio domain. It was demonstrated that lithofacies discrimination was still possible even on relative parameters similarly to what is shown in Figure 9. The same analyses was carried out, at seismic scale, by plotting the Acoustic Impedance vs Poisson's ratio extracted from the inverted data. It was verified that the range of the relative parameters values obtained from inversion was strongly different from the ones derived by well model (Figure 12).

A statistical solution was found by rescaling the distribution of the seismic cluster points from relative elastic parameters (grey cloud in Figure 12), by matching the well. Scalars were applied on inversion output datasets in order to make the well-based relative Acoustic Impedance – Poisson's ratio template quantitatively useful for lithology classification. The template can be visualized as a pdf (probability density function), and fully used in order to achieve a probabilistic classification (Figure 13).

Figure 14, Figure 15, and Figure 16 show an example of lithology probability sections, and a “dominant” lithofacies section (Figure 17). This latter product is based on the concept of “highest probability” or “winner facies”, meaning that the lithological volume representation is based on the most likely solution from a classification probabilistic approach

Conclusions

A quite challenging project was performed, in order to compute a lithofacies probabilistic model starting from seismic data, in a virgin area, by integrating Electrofacies and PetroElastic analysis from an adjacent, but different basin. Lithofacies probability volumes are the main results of the integration process.

Acknowledgement

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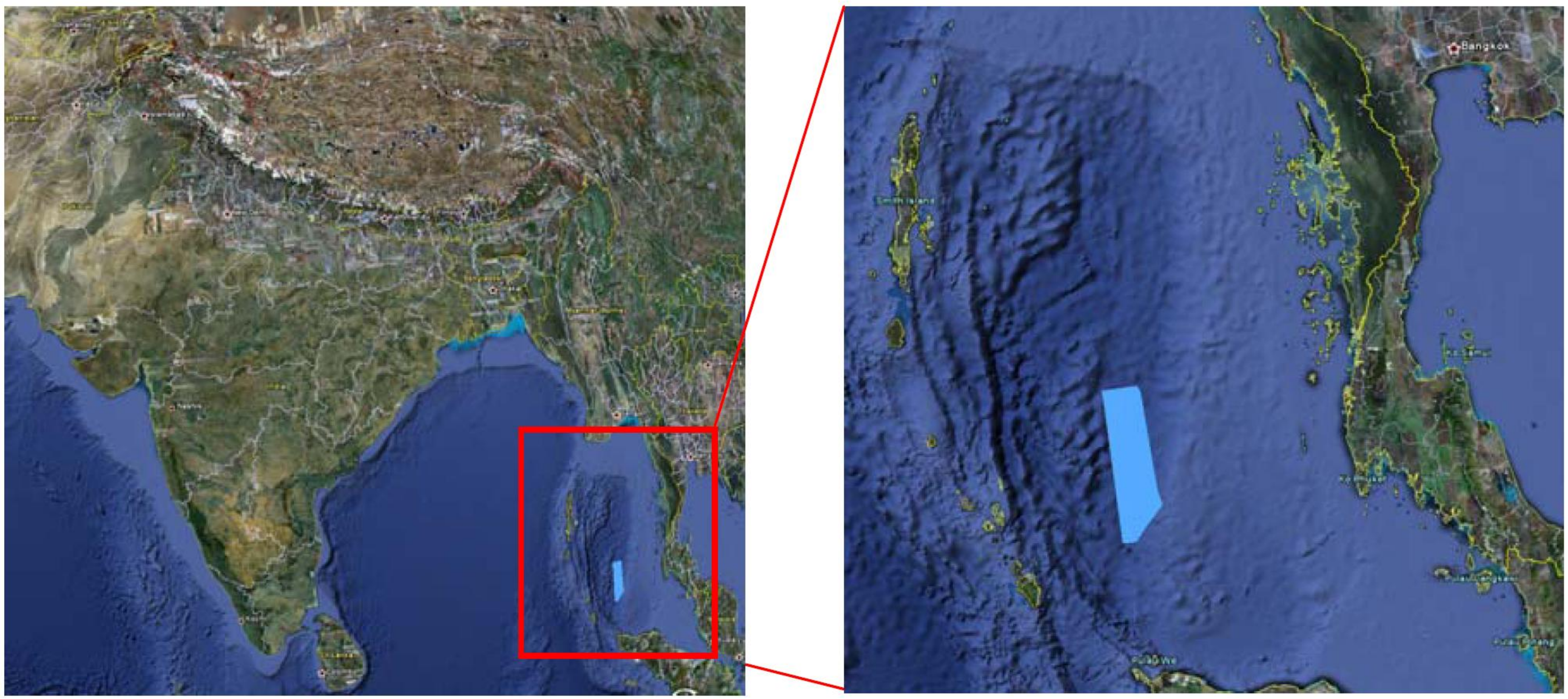

Figure 1. Location of East Andaman Basin in Andaman Sea.

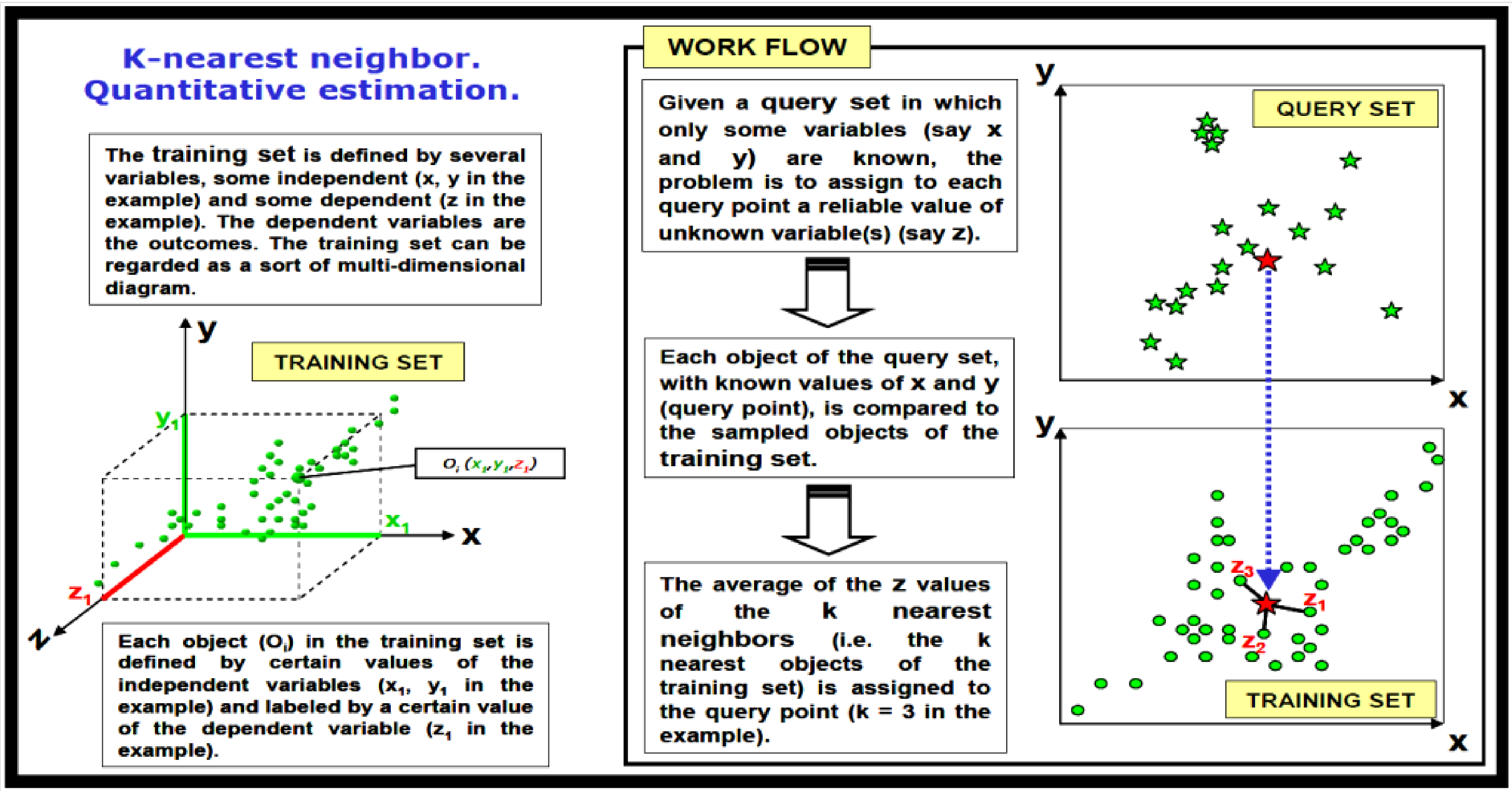

Figure 2. Key Nearest Neighbour methodology.

	NAME	COL	PAT	WEIGHT	GR_COR	DT	NPHI_COR	RHO_COR	DNDIF
1	LMST1–LPOR			648					
2	LMST2–HPOR			161					
3	GAS SDST			337					
4	SDST–LPOR			3955					
5	SD1–MPOR			7374					
6	SD2–HPOR			539					
7	SLST1–LPOR			3761					
8	SLST2–MPOR			6847					
9	SLT–HPOR			2393					
10	SH1–HCOMP			8476					
11	SH2–MCOMP			4096					
12	SH3–LCOMP			1272					

Figure 3. Final Electrofacies Model.

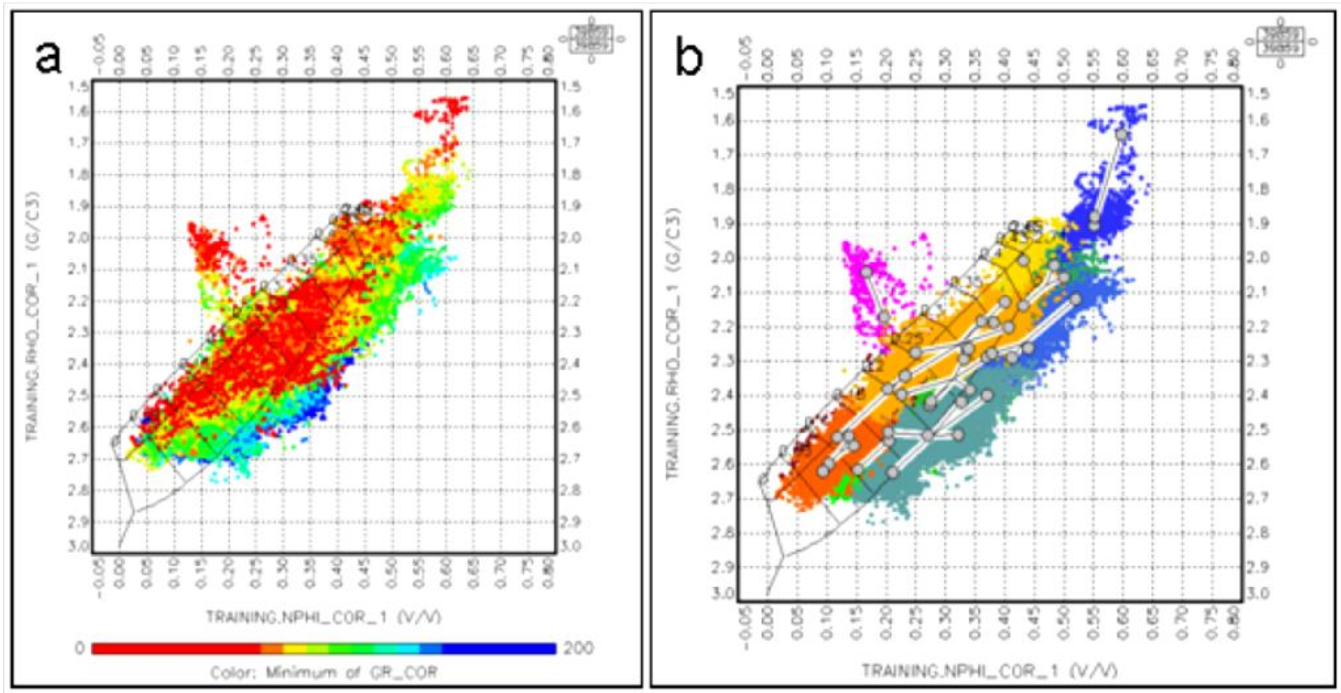

Figure 4a. Density-neutron cross plot. (a) Data distribution (color scale: gamma ray); (b) Electrofacies characterization.

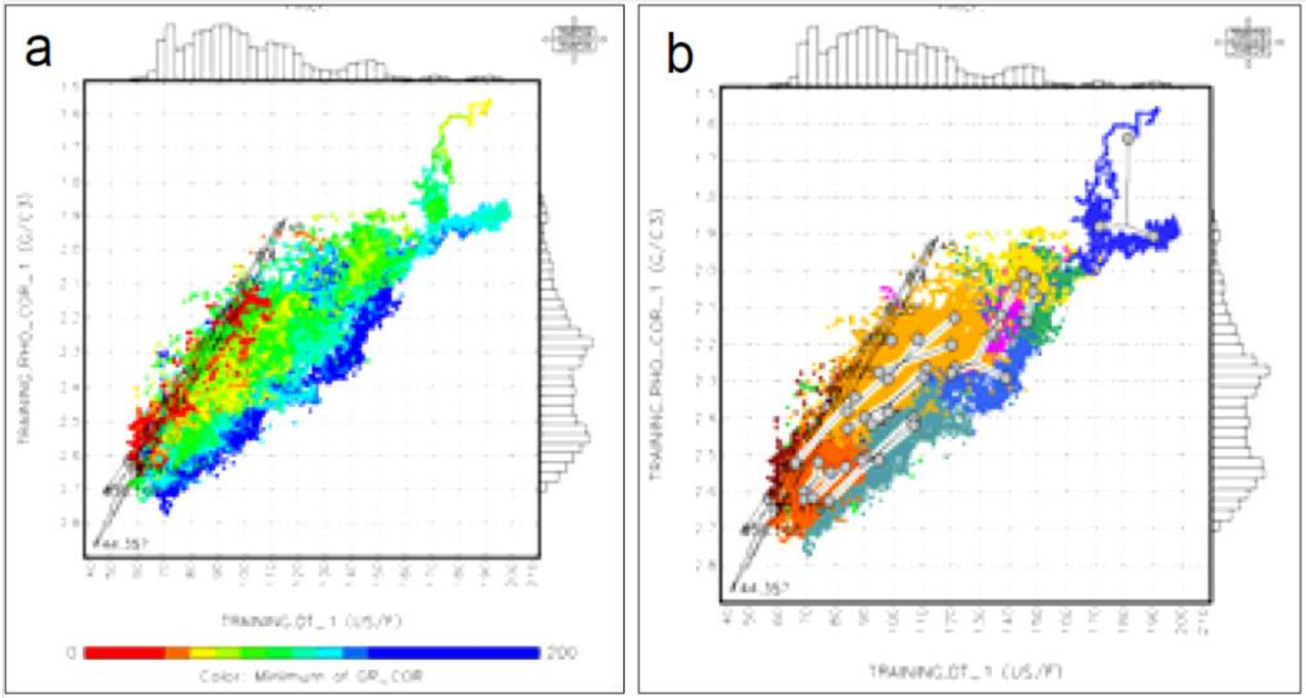

Figure 4b. Density-sonic cross plot. (a) Data distribution (color scale: gamma ray); (b) Electrofacies.

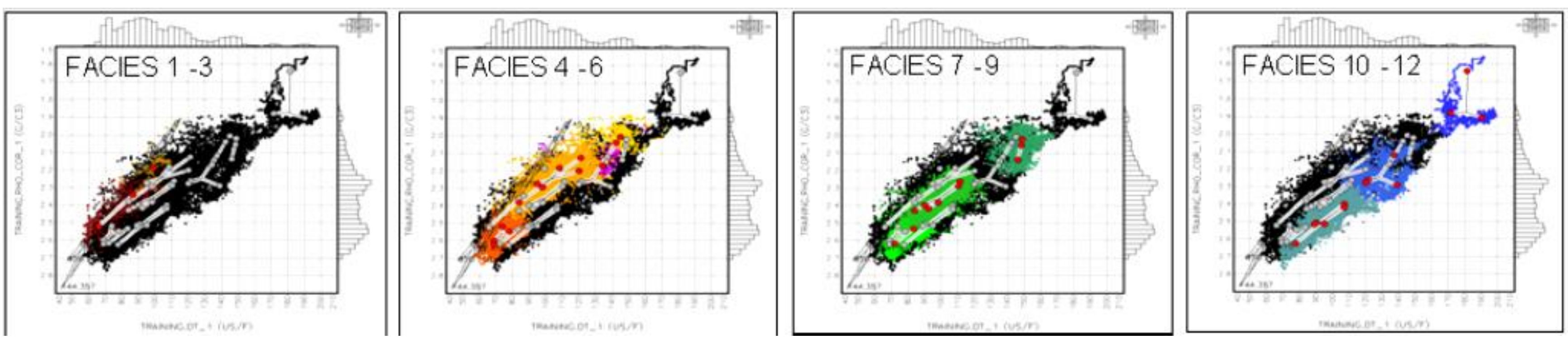

Figure 5. Density-sonic cross-plot. Characterization of the main electrofacies groups. Within each group, the single facies are aligned along a unique sonic-density trend.

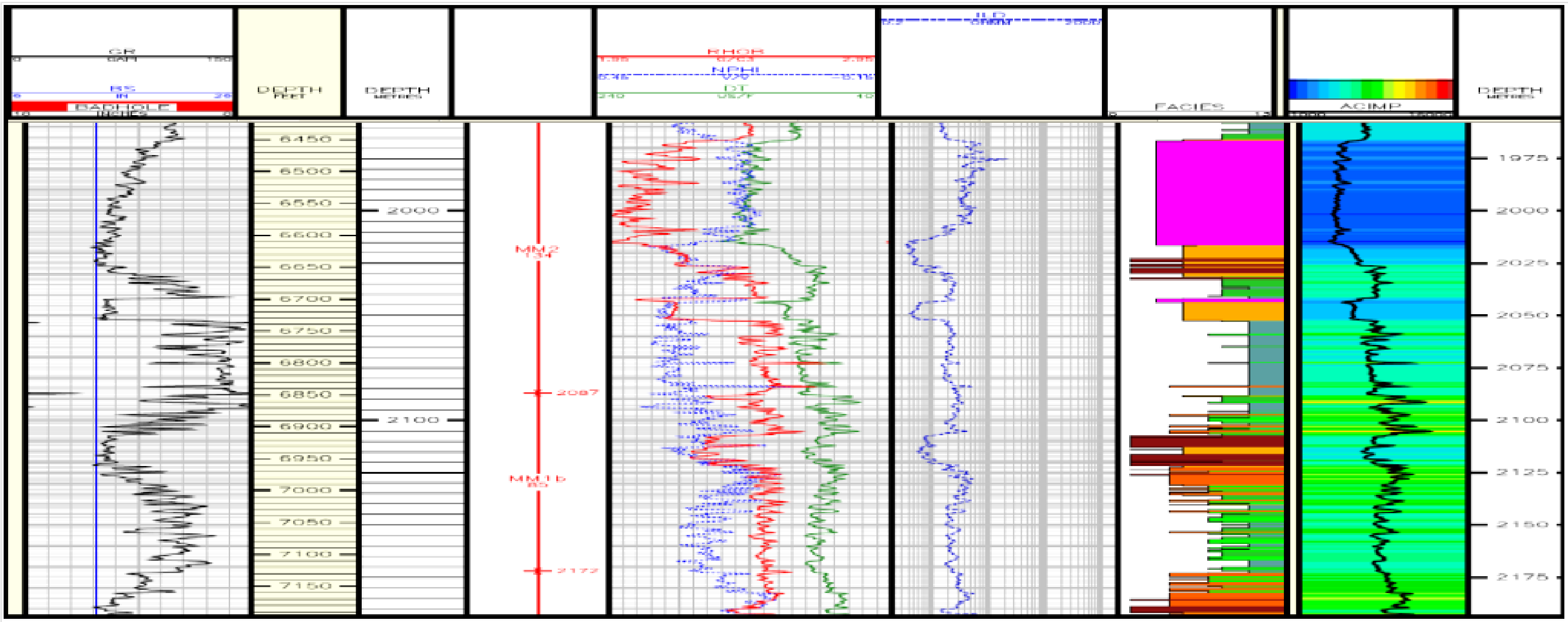

Figure 6. Composite Log of a Well Chosen for the study.

Figure 7. Cross Plot Vp vs Density colored with well Gardner Law: hob=0.31*Vp^0.253

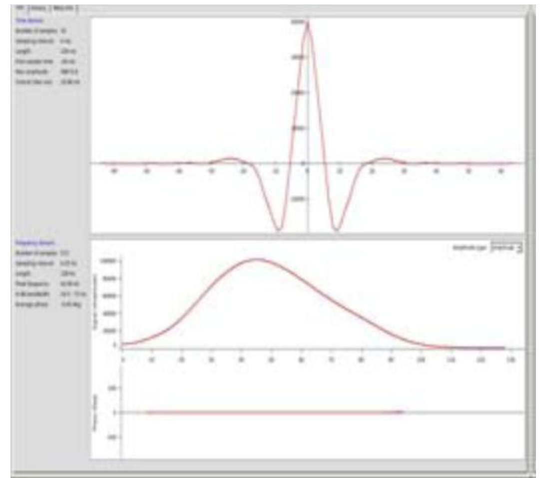

Figure. 8 Statistical Wavelet Extraction.

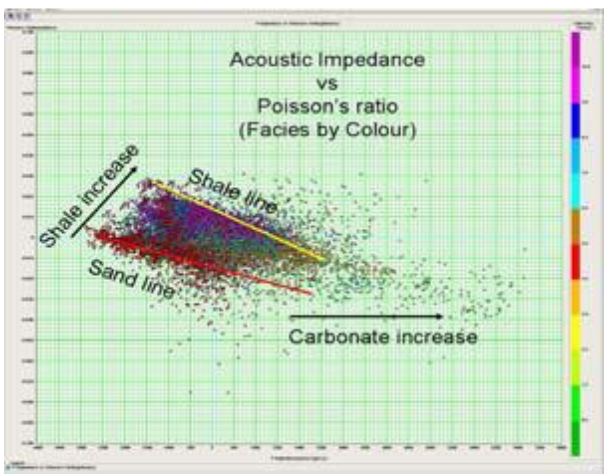

Figure 9. PetroElastic crossplot, showing Electrofacies distribution on Ip-PR domain.

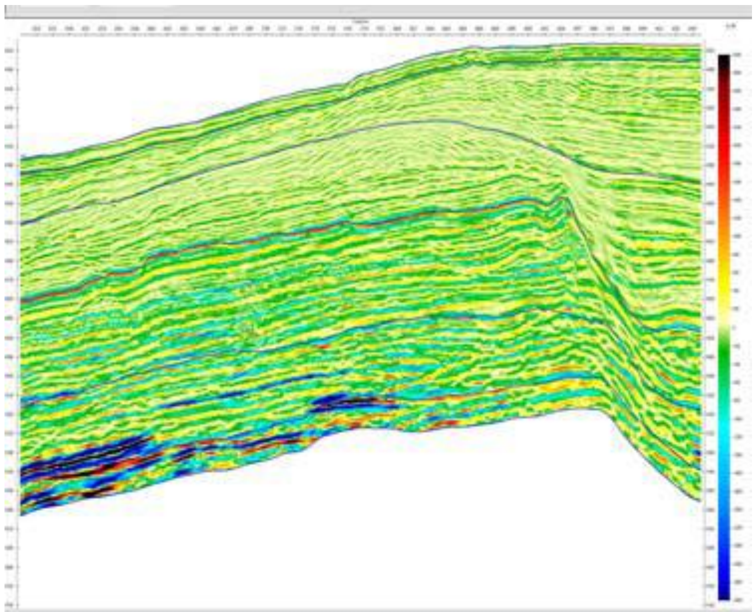

Figure 10. W-E profile of Rel Acoustic Imp. Volume.

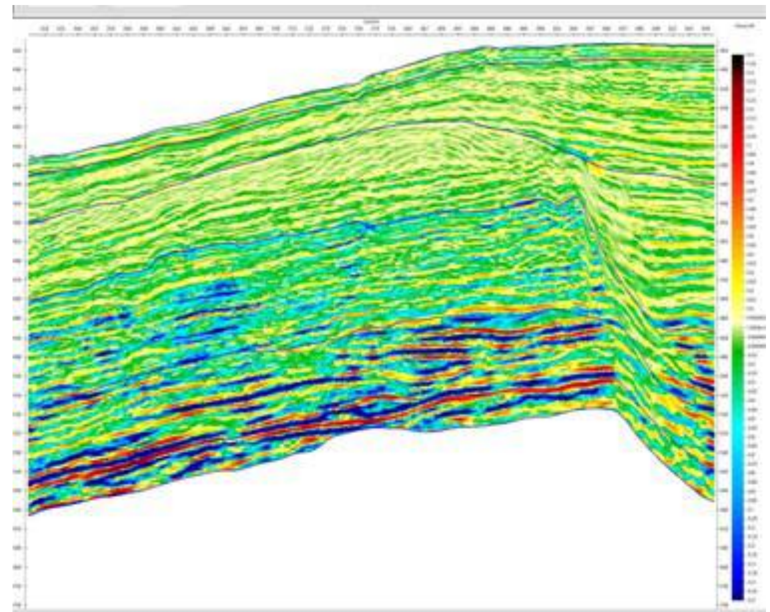

Figure 11. W-E Profile of Rel Poisson Ratio Volume.

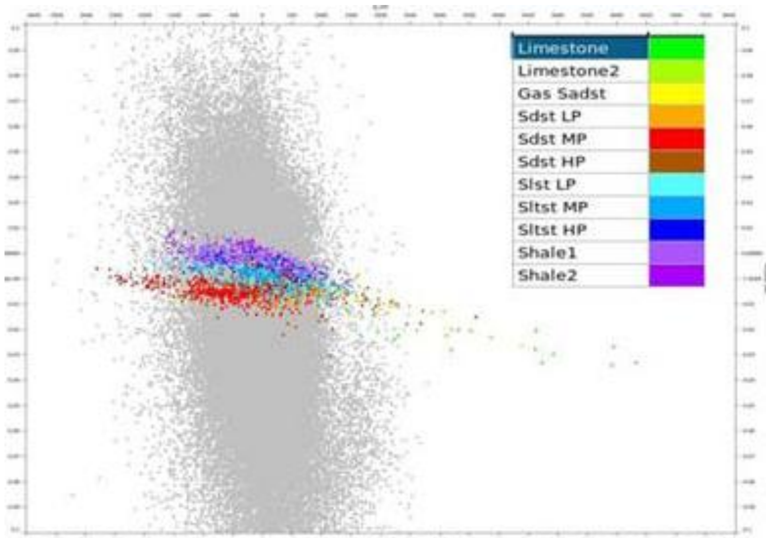

Figure 12. Ip-PR crossplot of Seismic (grey) vs Well (colour) data.

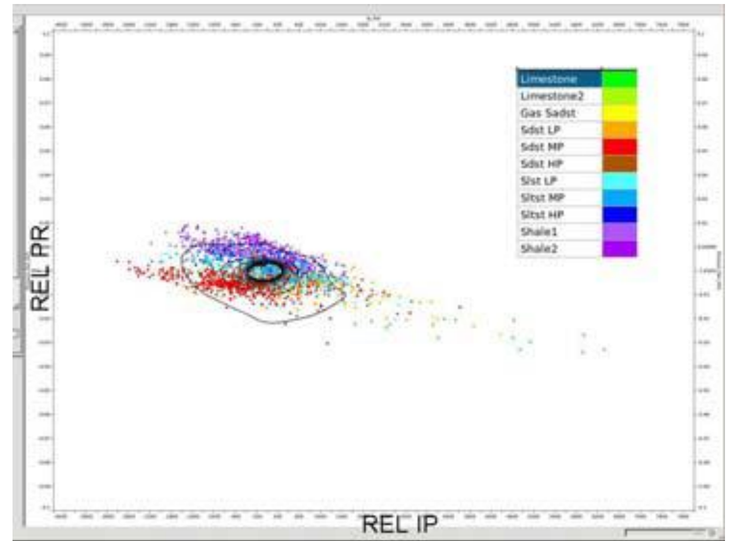

Figure 13. Facies probability density function (pdf).

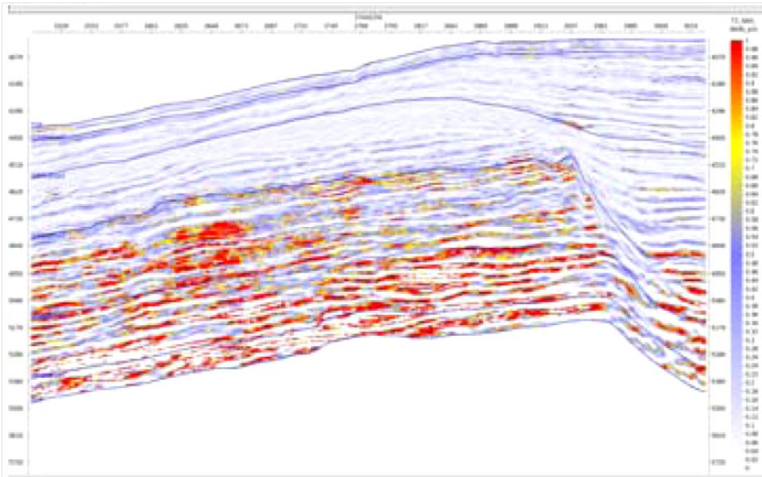

Figure 14. W-E profile of Sandstone Probability Volume.

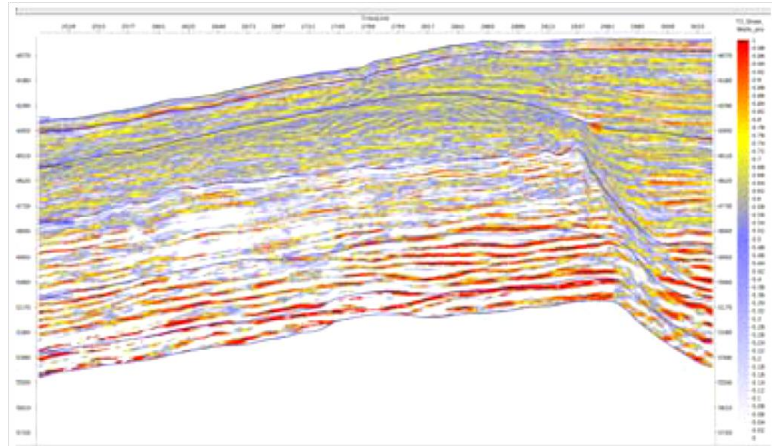

Figure 15. W-E profile of Shale Probability Volume.

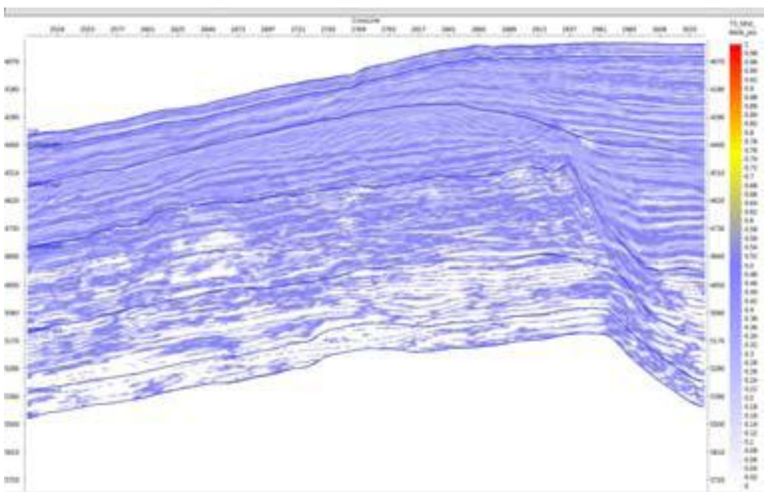

Figure 16. W-E profile of Siltstone Probability Volume.

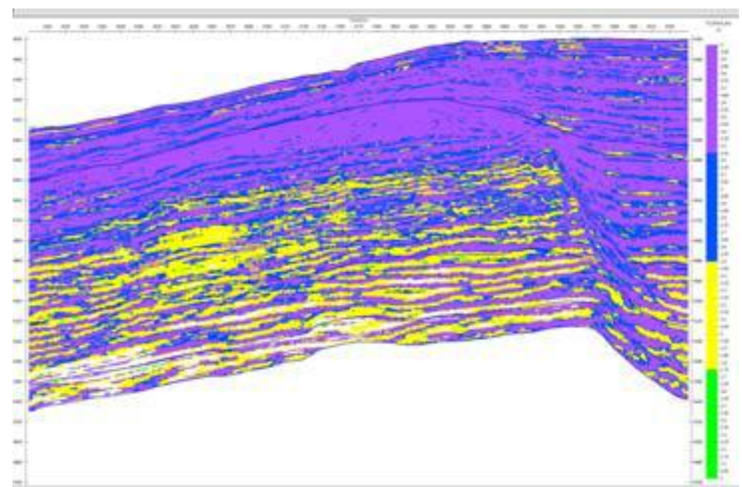

Figure 17. W-E profile of most probable facies volume.