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VACA MUERTA FACIES MODELING IN LOMA CAMPANA PART 1: ELECTROFACIES

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RESUMEN

Modelado de facies de Vaca Muerta en Loma Campana – Parte 1: Electrofacies

El que la Formación Vaca Muerta tenga un importante espesor, por encima de 300 m en muchas partes de la cuenca, tiene efectos tanto positivos como desafiantes. Aunque el alto espesor proporciona grandes volúmenes de recursos y el potencial para el desarrollo de múltiples intervalos, la selección del punto de aterrizaje para los pozos horizontales presenta numerosas opciones. En esta contribución, se han integrado electrofacies (1D) basadas en registros eléctricos de pozos con productos de inversión sísmica 3D, para determinar tipos de roca, entender su distribución 3D y poder predecir e identificar puntos de aterrizaje óptimos en el área de Loma Campana. Basado en el método de clustering multi-resolución basado en gráficos (MRGC) y utilizando registros básicos de pozos (neutrón, densidad y tiempo de tránsito compresional como dato de entrada) en 8 pozos verticales, se desarrolló una clasificación de electrofacies para el intervalo estratigráfico Vaca Muerta – Quintuco, la cual fue extrapolada a aproximadamente 75 pozos. El análisis de clusters permitió definir 8 electrofacies; 5 de las cuales se relacionan con facies orgánicas de Vaca Muerta y 3 se relacionan con facies carbonáticas de Quintuco. Las electrofacies representan distintas propiedades de la roca que incluyen carbono orgánico total (TOC), porosidad, volumen de carbonato, impedancia acústica y módulo de Young, entre otros. Los rangos de valores de cada propiedad modelada fueron verificados con resultados de laboratorio.

Una vez generadas las electrofacies, se establecieron límites de impedancia acústica (IA) para cada una de las 8 electrofacies, los cuales fueron correlacionados con un volumen de impedancia invertida de la sísmica 3D, obteniéndose 8 facies sísmicas de IA vinculadas a rangos discretos de propiedades de roca. Debido a la limitada resolución sísmica de algunas capas delgadas y a la complejidad estructural en la base de Vaca Muerta, los coeficientes de correlación hacia la base son menores, pero aumentan hacia el *toe* y *foresets* de la clinoforma de Vaca Muerta (sección progradante). En base a este enfoque integrador, se puede distinguir claramente entre unidades ricas en carbonato y unidades ricas en materia orgánica, permitiendo ser más predictivo en la selección de intervalos de navegación de pozos horizontales. Esta clasificación no solo refleja las variaciones verticales, sino que también refleja variaciones laterales en toda el área de Loma Campana, validando el modelo en diferentes ventanas de fluido.

INTRODUCTION

During the analysis of additional targets within the Loma Campana area, the necessity of characterizing in detail the entire organic section became critical. Following a data integration approach to maximize the learnings, rock lab results, e-logs from vertical wells and seismic inversion data were considered.

Previous facies workflows were already generated for the area (Gonzalez Tomassini *et al.* 2017; Bernhardt *et al.* 2017; Reijenstein *et al.* 2017; Vittore *et al.* 2016 and Vittore *et al.* 2014), but none of them were applied to guide seismic inversion facies as it is proposed in this study.

Electrofacies in general is defined as a group of rocks with similar logs responses. Those responses could represent diverse features such as texture, lithological composition, color, fossil content or another attribute. In this case, the electrofacies generated needed to reflect different rock properties such as porosity, TOC content, carbonate volume and elastic properties (Young Modulus and Poisson Ratio). It was critical that those electrofacies would correlate with distinct acoustic impedance (AI) values in order to be able to upscale them to the seismic data.

METHODOLOGY

A complete set of laboratory studies was performed on 76 rotated sidewall cores from 2 vertical wells in the Loma Campana field. Those lab studies included organic and inorganic quantification of the matrix components (TOC and X-Ray Diffraction) and pore volume measurements. Additionally, several complementary studies were done to characterize pore type and size: Subcritical Nitrogen Gas Absorption (SGA) and Scanning Electron Microscope (SEM) (Crousse *et al.* 2018, Formation Evaluation symposium in this conference). Lab results were used as validation of TOC, mineralogy and porosity logs generated using a deterministic petrophysical model (Cuervo *et al.* 2016).

The curves selected to generate the electrofacies were basic ones to maximize the number of wells containing that logging suite. Another criterion was to use raw curves and not modelled

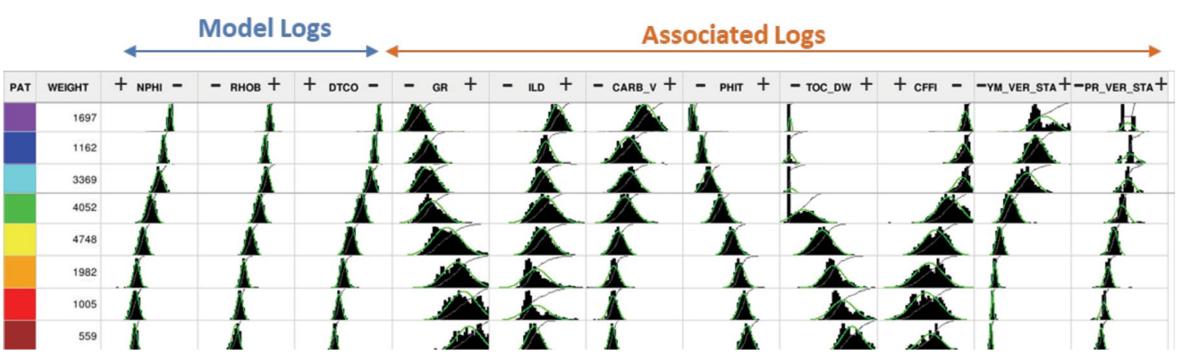

Figure 1. Table showing model and associated logs for each electrofacies. Histograms represent raw and interpreted logs value ranges.

ones. Among the basic logs, neutron, density and compressional sonic were chosen based on previously proven relations with porosity, carbonate volume and TOC (Cuervo *et al.* 2016).

To understand the characteristics of each facies, "associated logs" were incorporated. These curves were used only as comparison, so a visualization of the value range of each parameter was made, for better defining which rock properties were reflecting. The associated curves were: gamma ray, porosity, TOC, free fluid from nuclear magnetic resonance (NMR), carbonate volume from model, deep resistivity, Poisson Ratio and Young Modulus (Figure 1).

For this study a multi-resolution graph-based clustering (MRGC) method was selected. MRGC automatically determines the optimal number of clusters, *yet al*lows the geologist to control the level of detail needed to define the electrofacies (Ye and Rabiller 2000).

This clustering method presents several advantages such as reliability in processing very complex data configurations, capability to recognize natural partitions of log data that may reveal the organization of geological facies and being independent to a priori knowledge of the data set.

MRGC method proposes to the user several optimal numbers of clusters corresponding to different resolutions. In addition, the results of MRGC are organized in hierarchical way so that the clusters of higher resolutions are always sub-clusters of the low-resolution clusters. Such a hierarchy corresponds to the way that geologists organize facies. These multiresolution and hierarchical properties help a lot with the electro-facies interpretation.

One of the possible results is chosen based on the resolution at which a user would like to analyze the data, and later by merging small clusters into electrofacies to which geological characteristics are assigned.

The selected training wells, present good raw log quality, include free fluid from NMR and were areally distributed. As a result, 8 electrofacies were obtained in 73 wells, covering the entire area. The electrofacies cover from organic-rich Vaca Muerta to tight and lean Quintuco rocks. Figure 2 and Table 1 show input logs value ranges for each one of the electrofacies.

Notice that some electrofacies (red and brown, cyan and blue) present close values. With the goal of characterizing heterogeneities in a single well, a lumped version of the electrofacies could be used. On the other hand, if focus is on areal reservoir properties variation, a set of 8 electrofacies is preferred.

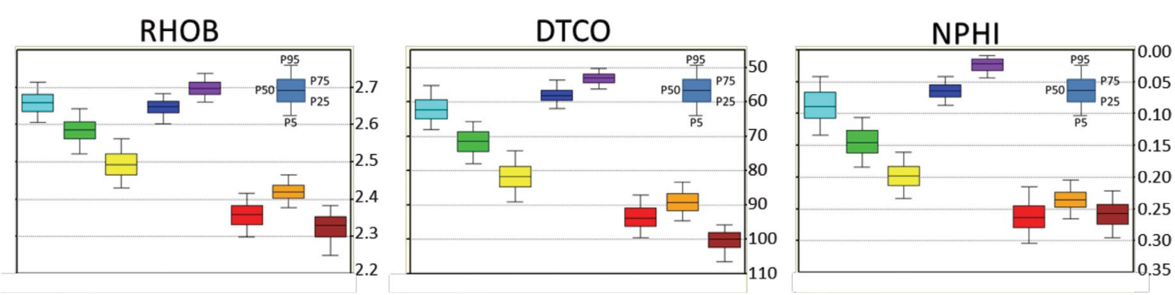

Figure 2. Frequency plots for input logs colored by the 8 electrofacies in 73 Loma Campana wells.

EFacies		Purple	Blue	Cyan	Green	Yellow	Orange	Red	Brown
RHOB (g/cm3)	Mean	2.699	2.646	2.660	2.584	2.494	2.420	2.356	2.322
	Standard Deviation	0.242	0.025	0.038	0.038	0.041	0.027	0.037	0.051
DTCO (µs/f)	Mean	53.377	57.769	61.912	71.649	81.615	89.054	94.302	100.272
	Standard Deviation	2.182	5.258	3.893	3.963	4.541	3.418	4.129	3.429
NPHI (v/v)	Mean	0.024	0.065	0.087	0.145	0.197	0.235	0.262	0.259
	Standard Deviation	0.011	0.015	0.028	0.025	0.023	0.019	0.026	0.024

Table 1. Mean and Standard Deviation values for each electrofacies.

To ensure feasibility to tie electrofacies with seismic inversion, acoustic impedance was calculated in the wells. Each facies showed an AI specific range, validating the workflow (Figure 3). For details on how those electrofacies helped to guide facies population on the static model, refer to Reijenstein *et al.* (2018, this conference)

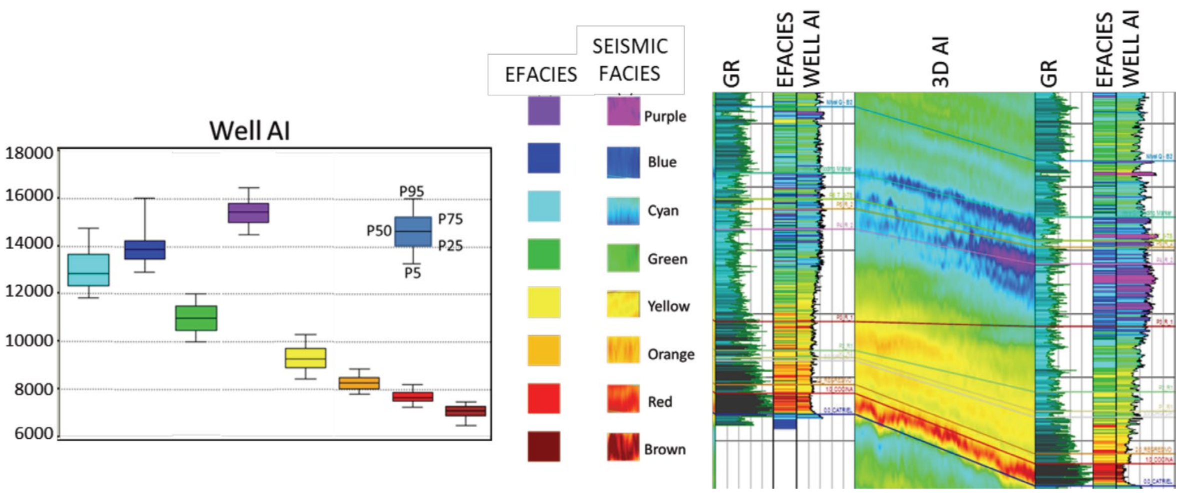

Figure 3. On the left, well Acoustic Impedance (AI) values for each electrofacies. Those value ranges were used to build color palette for Seismic Inversion. On the right, correlation among E-facies, well AI and 3D seismic AI.

RESULTS

From the 8 electrofacies defined for the studies area, 5 (brown, red, orange, yellow and green) correspond to the organic rich Vaca Muerta interval (TOC higher than 2w%) and 3 (cyan, blue and purple) correspond to the carbonatic organic-lean section of Quintuco Fm. As presented in figure 4, warmer colors are characterized by higher TOC, porosity and free fluids.

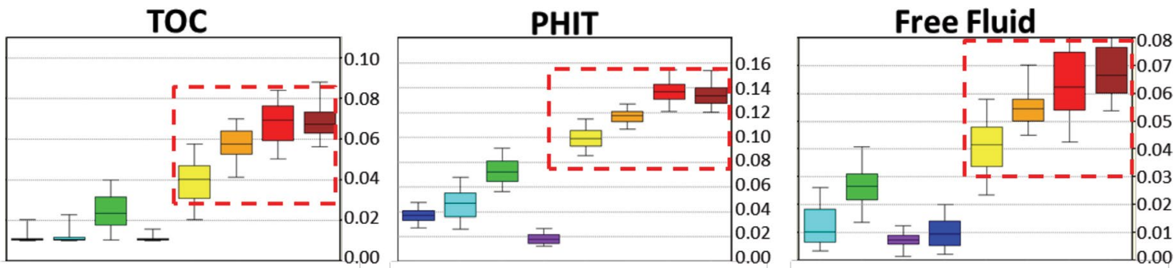

Figure 4. Plots showing TOC, Total porosity and Free Fluids value ranges for each electrofacies. Red box highlights electrofacies with higher values.

These electrofacies fulfil the objective of providing an extra tool to identify and prioritize numerous landing points, typical of Vaca Muerta formation. Figure 5 illustrates how electrofacies show vertical heterogeneities, highlighting sections with better reservoir properties.

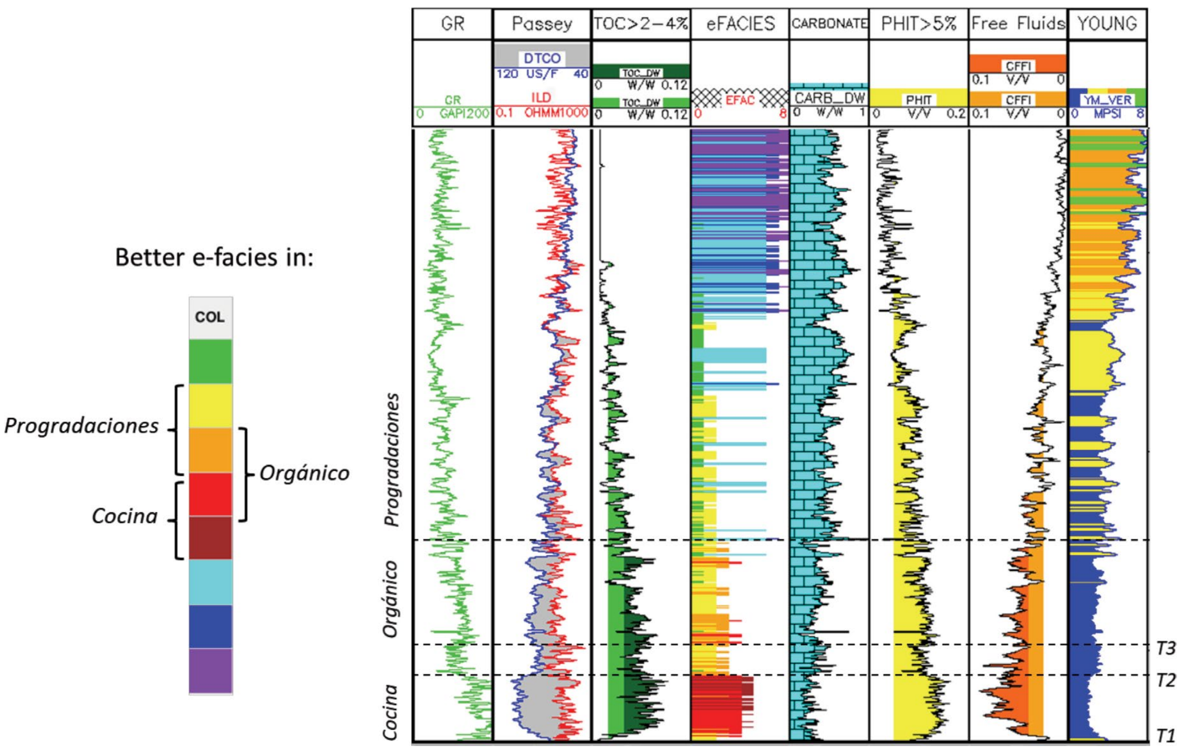

Figure 5. Vaca Muerta type well. Track 1: gamma ray, Track 2: Passey, Track 3: TOC, highlighted in light and dark green 2 and 4w% cutoff respectively, Track: electrofacies, Track 5: carbonate content, Track 6: porosity, Track 7: Free Fluids from NMR and Track 8: Young Modulus.

Lateral variation is well represented by these electrofacies. As figure 6 shows, organic rich interval getting thicker to the northwest is evidenced by an increment of warmer-color electrofacies presence.

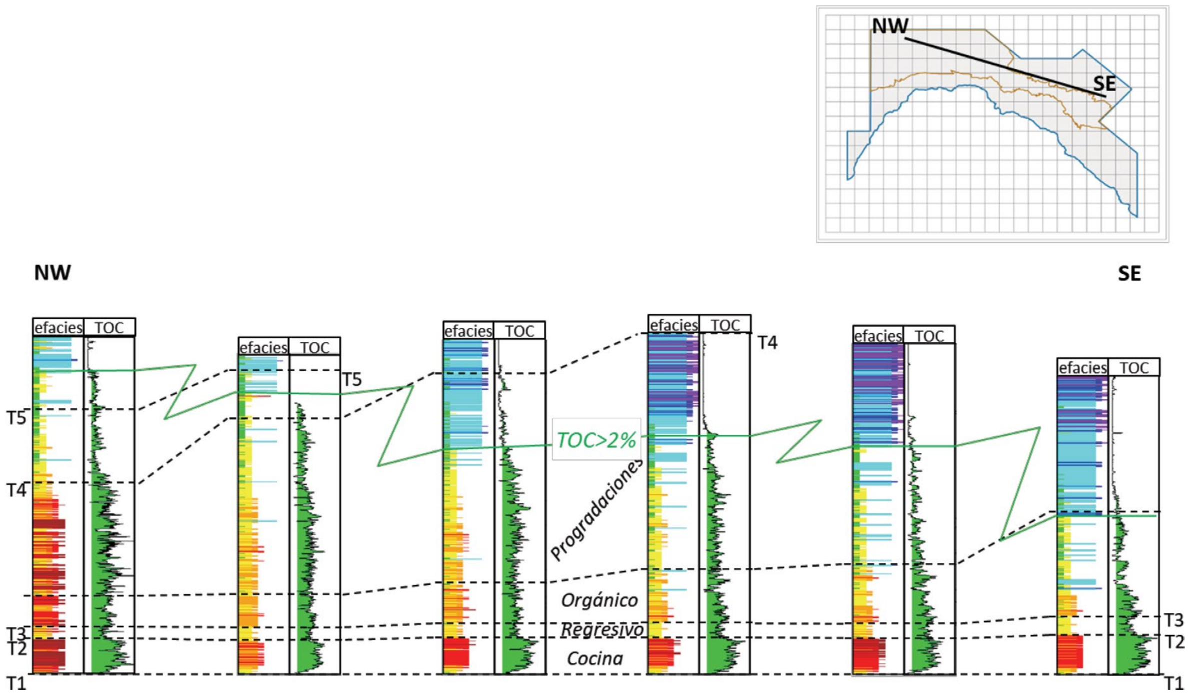

Figure 6. Northwest to Southeast well cross section. Track 1: electrofacies, Track 2: TOC, highlighted in green values higher than 2w%. Electrofacies brown, red, orange, yellow and green (representing TOC>2w%) are more abundant towards northwest area.

The numerous laboratory studies, special logs interpretation and outputs from petrophysical model, allowed to define for each electrofacies the mineralogy, TOC, total porosity, elastic properties and free fluids. Additionally, a pore system characterization based on 2D and 3D scanning electron microscope, subcritical nitrogen gas absorption, T1-T2 maps from nuclear magnetic resonance and textural parameter form dielectric dispersion log was done. This study included pore typing description and quantification. Organic matter hosted pores (OMphi) were discriminated from the inorganic matrix hosted pores (IMphi), which could be intraparticular or interparticular. Pore sizes and connectivity were analyzed too (Crousse *et al.* 2018). Figure 7 shows a summary of some of these rock properties for each electrofacies.

Brown and red electrofacies present very high organic content and porosity, and low carbonate volume. Average organic pores can reach 50% of the total pore volume. Small and big organic pore diameter can be present in these types of rocks. Inorganic pores types can be interparticle and intraparticle, typically with a small to medium diameter. Big pores between clay flakes are very common.

Orange electrofacies represents organic rich rock with low carbonate content and high porosity. Pores are connected (based on 3D SEM) and inorganic pores predominate slightly over organic pores. Organic pores dominant diameters are small to medium. Inorganic pores are mainly interparticle with small and big sizes. Big pores between clay flakes are very common.

Yellow electrofacies has a medium organic content and well-connected pores. Compared to brown, red and orange electrofacies, this rock type presents less pore volume and higher carbonate content. Inorganic pores predominate over organic pores. Small organic pore sizes are not present. Inorganic pores are interparticle and mostly small. Medium to big inorganic pores can be found between clays.

Green electrofacies contains the lowest organic content. Pore volume and connectivity decrease significantly while carbonate content increases. Inorganic interparticle porosity is the main pore type with small to medium diameters. Organic pores are medium in size.

Cyan, blue and purple electrofacies are carbonatic and organic lean rocks with low porosity. Dominant inorganic and interparticle pores are small and non-connected.

EFacies	TOC % (mean)	Carb vol % (mean)	PHIT % (mean)	Pore Type (average)	OMphi Size (area mode)	IMphi Size (area mode)
Brown	8	<30	14	50% OMPHI 50% IMPHI	Lot small & Big	Lot small inter/intraparticle Big between clays
Red	7	<30	13	50% OMPHI 50% IMPHI	Lot small & Big	Lot small-med inter/intraparticle Lot Big between clays
Orange	6	30	12	40% OMPHI 60% IMPHI Connected pores	Lot small & Lot med	Lot small-big interparticle Lot Big between clays
Yellow	4	>35	10	30% OMPHI 70% IMPHI Connected pores	Lot med No small range	Lot small & Few med-big interparticle Med-Big between clays
Green	3	>40	7	20% OMPHI 80% IMPHI Connected & non connected pores	Med	Small & med interparticle
Cyan *Blue*	1	>50	4	10% OMPHI 90% IMPHI Non connected pores	Med	Small interparticle
Purple	0	>55	2	100% IMPHI	Med	Small

Small: 2-40nm Med: 80-300 Big>300nm

Figure 7. Reservoir properties for blue, cyan, green, yellow, orange, red and brown electrofacies.

CONCLUSIONS

The proposed electrofacies, proved to illustrate Vaca Muerta Formation heterogeneity in the studied area. These 8 electrofacies represent different reservoir properties such as TOC, pore volume, carbonate volume, pore type predominance and pore size.

A practical scale was achieved, providing additional information on vertical wells for landing point prioritization, highlighting additional targets and identifying rock properties lateral variation.

Electrofacies-acoustic impedance integration allowed defining 8 seismic facies that could be used for properties population in static models.

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