PDVSA INTEVEP | Paradigm®

Electrofacies Modeling: Using Multi-Resolution Graph-based Clustering (MRGC) Analysis in a Carbonate Field in Venezuela

The Challenge

This study was performed for PDVSA INTEVEP in a carbonate area located in a gas and condensate reservoir offshore Venezuela. The main challenge in the study was caused by the high heterogeneity of the rock fabric. In order to continue studying this reservoir, there was a need to understand how the pore system pattern reflects good porosities throughout the limestone but has significant permeability variations. The data was collected from wells with cores. The variations in the petrophysical properties are much harder to predict in wells without core data.

The heterogeneity in the carbonate section is the result of pore system variations and post-depositional alterations. Two units are clearly differentiated: the upper unit and the lower unit. The upper unit comprises coarse-grained limestone (rudstone), the preservation of primary and secondary porosities, which caused the distribution and size of variable pores, and a heterogeneous pore throat radius associated with the particle micro-fracturing contribution. This unit behaves as an "inter-particle" pore system. The lower unit comprises facies formed by grain and mud (rudstone and floatstone). Their preserved micro-porosities in some bioclasts and carbonate mud define the uni-mode pore distribution and size, with a small pore throat radius.

The main objective of this stage of the study was to apply Multi-Resolution Graph-Based Clustering in order to build electrofacies models and integrate them with sedimentological interpretations by extrapolating the models to wells without core data.

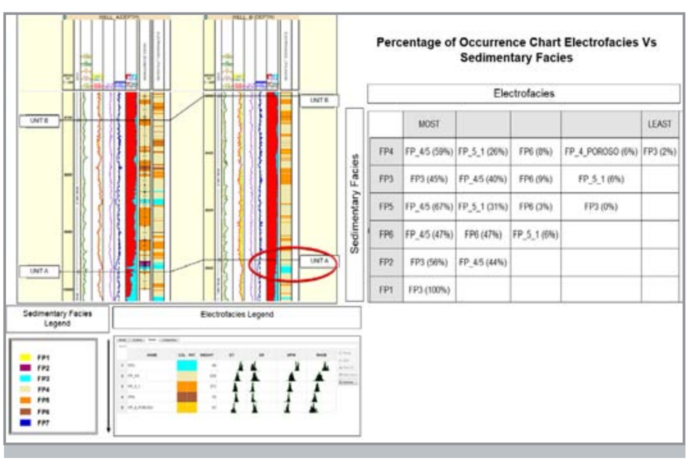
The Solution

The Multi-Resolution Graph-Based Clustering (MRGC) technology was proposed as part of the Paradigm® Geolog® NMR formation evaluation solution. MRGC clusters dot patterns due to changes in log behavioral responses using geostatistics and neural networks. These dot clusters, also known as electrofacies, are associated with changes in rock quality and were calibrated with core sedimentary facies.

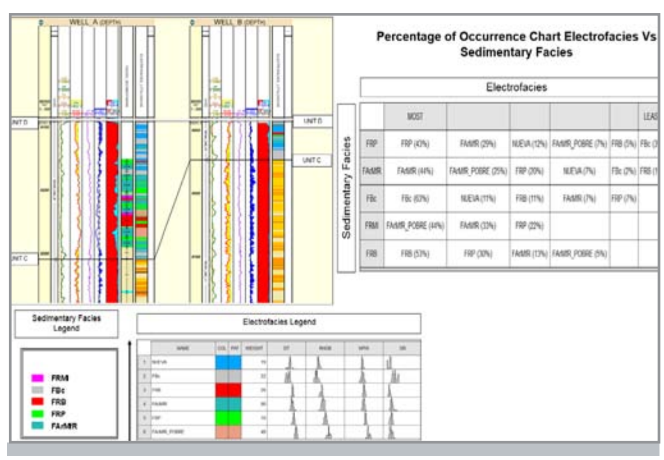
The following electrofacies models were built using the Geolog Facimage MRGC solution:

1. Electrofacies models were built from conventional logs calibrated with sedimentary facies in Well A (with core) and propagated to Well B (without core). A versatile approach to the cross-sectional analysis of graphics from logs uploaded into the model was applied to highlight the electrofacies associated with the heterogeneity changes in the carbonate section.

   The ideal number of electrofacies and cluster of similar dots were determined using statistical k-Nearest Neighbors and Kernel Index statistical parameters. The resulting electrofacies were calibrated to sedimentary facies described in contingency tables from core analysis; these tables showed the percentage of correspondence between electrofacies and sedimentary facies.



▲ Results of electrofacies model and comparison between electrofacies vs. sedimentary facies in lower unit



▲ Results of electrofacies model and comparison between electrofacies vs. sedimentary facies in lower unit

The electrofacies of the well with core data were propagated to a neighboring well with no core data, using neural networks. A stratigraphic correlation between wells was performed to adjust the depth of tops which could be used when tracking lithostratigraphic units.

Another model was developed using the same methodology: Electrofacies were built on the basis of the nuclear magnetic resonance log considering the time for transverse relaxation T2. The resulting electrofacies showed changes in the distribution of the pore size.

2) Textural electrofacies models were generated from resistive image logs calibrated with sedimentary facies, petrofacies and core porosity data in Well A. Efficient workflows were used to process and interpret resistive image logs for data preparation.

   A computerized statistical model was used. This model captures texture parameters from the image and does not require previous assumptions about texture type.

   The statistical model was defined by histograms and auto-covariance, which describe the contrast and spatial arrangement of basic patterns. Texture parameters were then organized and classified on the basis of their visual similarity.

   The workflow consisted of normalizing the image to remove low frequency variations in order to obtain an approximate symmetrical data distribution, centered around "0". Texture parameters were then captured from histograms and auto-covariance showing spatial variations. This statistical analysis was characterized through a "Feature Log". After texture parameters were obtained, a texture 1D map was extracted and the MRGC method was applied to find electrofacies resulting from the relationship and clustering of patterns observed in the 1D map in relation to the "Feature Log".

3) Permeability prediction in Well B based on the electrofacies model of Well A: The electrofacies model was built, taking into consideration the conventional logs available in both wells. For example, the core permeability of Well A was uploaded.

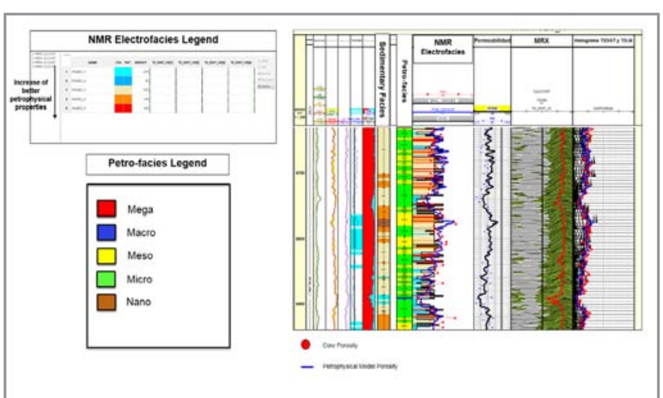
   The permeability prediction using MRGC and neural networks was based on training the statistical distribution of the core permeability of Well A for each electrofacies. The model was then propagated to Well B and the permeability prediction curve was obtained.

Paradigm Solutions Used

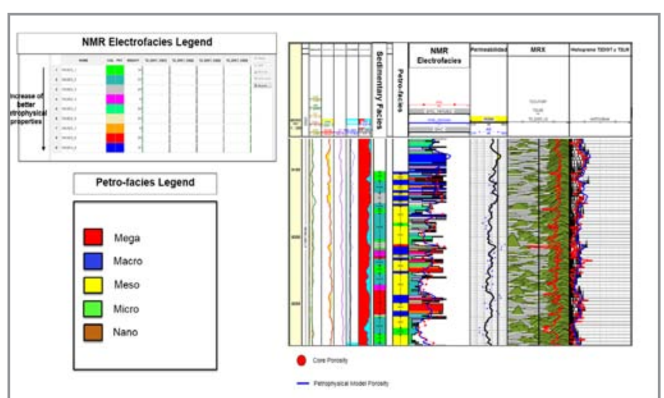
The Paradigm Geolog product suite was used to perform the workflows, resulting in an excellent electrofacies reproduction of the sedimentary facies of the core. A variety of well data, such as conventional logs, special logs, core data and sedimentology information, were integrated. The Geolog modules used included:

- Facimage to build the electrofacies models
- Geolog Correlator to create stratigraphic sections
- Determin to obtain a petrophysical model
- Geolog Image Log Processing & Interpretation to process the resistive image log

The Paradigm office in Venezuela offered specialized support to PDVSA INTEVEP For generating the workflow and applying Geolog in order to ensure optimal results. Support was available onsite, via e-mail and over the phone.



▲ Results of NMR electrofacies model and comparison between NMR electrofacies and petrofacies in lower unit (Well A)



▲ Results of NMR electrofacies model and comparison between NMR electrofacies and petrofacies in upper unit (Well A)

The Results

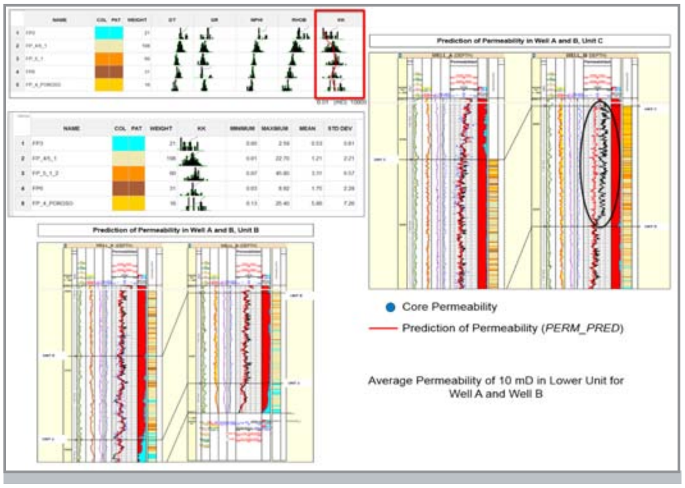
Based on the heterogeneity of the carbonate section, two electrofacies models were built: One for the upper unit and one for the lower. The MRGC method used for the lower unit in Well A resulted in several models. Selecting only one model depended on the degree of detail desired when defining the electrofacies. The 14-electrofacies model was the one that best reproduced the electrofacies clustering. These 14 electrofacies were then clustered and integrated with the sedimentary facies previously defined in the cores. A final model of 5 electrofacies was obtained.

The electrofacies model for the upper unit initially included 13 electrofacies. After observing the statistical distribution and sedimentary facies, electrofacies with a similar trend were clustered into a definitive 6-electrofacies model, with an average 50% match with the facies described in the cores. A "new" electrofacies was determined, which is located towards the top unit and is different from the others in relation to the variations observed on the input logs. This electrofacies has good petrophysical properties but it could not be compared to existing facies due to the lack of cores in that carbonate section.

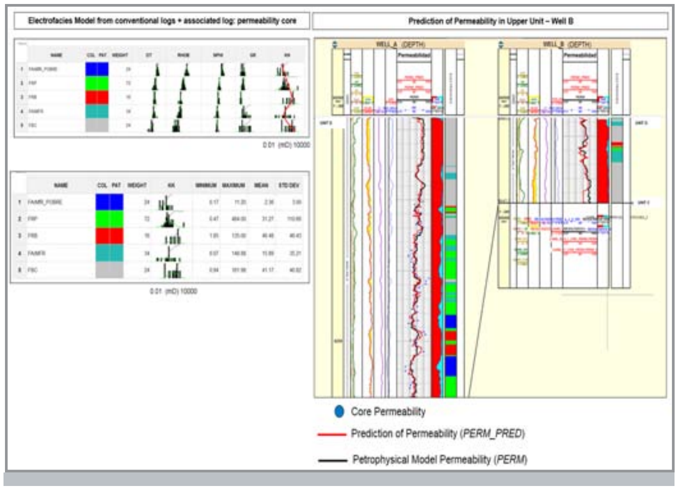
The five electrofacies built for the lower unit had an approximate 60% match with the sedimentary facies. Facies FP1 y FP7 could not be reproduced in this model due to the reduced thickness in their core. Facies FP2 was not significantly different from the electrographically obtained response for facies FP3.

The presence of the electrofacies FP3 in Well B was easily reproduced towards the top of Unit A. This could be useful when following up the lithostratigraphic units to be tracked inside the limestone. Therefore, the study suggested reviewing that top.

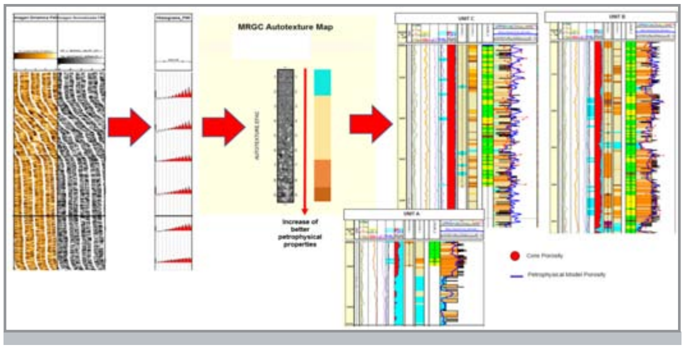
The pore size distribution electrofacies resulting from Nuclear Magnetic Resonance also showed a better rock quality electrofacies towards the top of the upper unit. In general, the electrofacies model with Nuclear Magnetic Resonance showed good correspondence with the porosity estimated in the petrophysical model, the core porosity and permeability, the sedimentary facies, and the petrofacies. This texture electrofacies model gave a good representation of changes in the heterogeneous areas as relates to porosity, permeability and distribution of the pore throat radius.



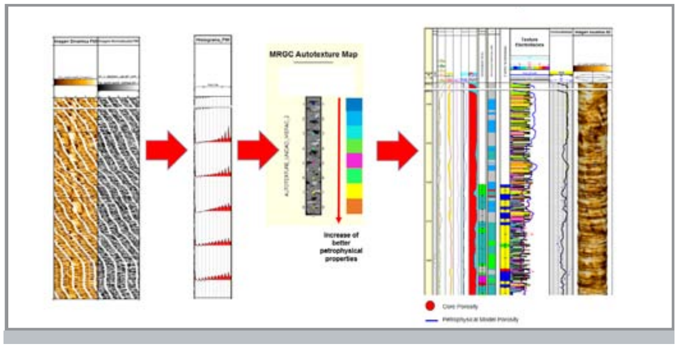
Prediction of permeability in lower unit (Wells B and A)



Prediction of permeability in upper unit (Wells B and A)



Results of texture electrofacies model and comparison with core porosity and petrophysical model porosity trend in lower unit (Well A)



Results of texture electrofacies model and comparison with core porosity and petrophysical model porosity trend in upper unit (Well A)

Texture electrofacies obtained with a resistive image log through a histogram analysis and auto-covariance matrix, followed by MRGC analysis, showed a good correspondence with the porosity estimated from the petrophysical model, the core porosity and the sedimentary facies, as represented in facies FP3 and FP5.

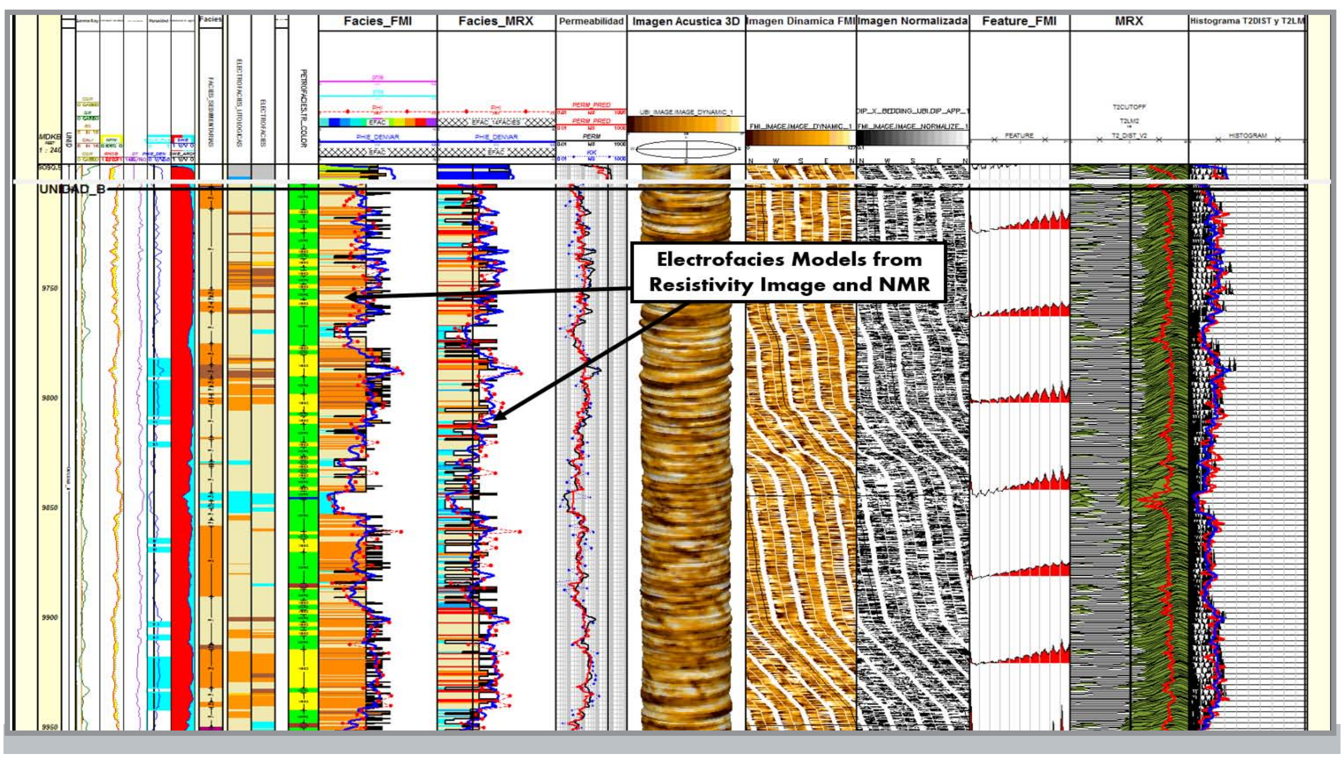
The permeability prediction based on MRGC and neural networks for Well B was very similar to the permeability estimated in the petrophysical model for units A, B and D. In unit C, the permeability prediction was lower than the permeability of the petrophysical model, since Well B showed better petrophysical properties (porosity and permeability) than Well A for that carbonate unit.

The Benefits

Through analyzing the neighboring ratio K and representative Kernel index, the MRGC method allowed the user to obtain clusters and ideal electrofacies numbers for defining lithological electrofacies from conventional logs, texture electrofacies from Nuclear Magnetic Resonance logs and resistive images, and also permeability prediction for wells without core data.

This robust and integrated tool enabled prediction about permeability and facies changes related to rock quality in wells without core data. The changes in rock heterogeneity were also observed in the Nuclear Magnetic Resonance and resistive image logs. Together, the electrofacies model allowed the client to propose a review of the lithostratigraphic tops. Project lead time was reduced due to use of the integrated Geolog formation evaluation package.

> *"Geolog is a versatile tool that enables us to load and manage the latest generation of well logs in a single interface. With Geolog, we can work with more information than with any other platform. We believe Geolog offers the best solution for petrophysical interpretation in a user-friendly software application."*
>
> Zureisy Marin, Petrophysicist, PDVSA INTEVEP



Integrated results in Well A