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Pore to Grid Carbonate Rock-Typing

Michel Rebelle, SPE, François Umbhauer, SPE, and Emmanuelle Poli, TOTAL, CSTJF, Pau, France

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Abstract

Often considered as a complex task, rock-typing in carbonates comes down to achieve reconciliation between various sources of data, including high resolution logs, representative core data and dynamic data.

The simplest statistical relationship between petrophysical classes and geological facies should be sought for.

More than 30 years of experience in carbonate fields has reinforced TOTAL's expertise leading to a specific rock-typing workflow through upscaling management of all available information from pore to plug, plug to core, core to log and log to model grid-cell.

This paper details the 8 main steps of a Rock-Typing workflow which is indifferently supported by in-house or commercial softwares.

Introduction

The main Rock-Typing studies objective is to contribute to build a predictive dynamic model by an accurate 3D-distribution of geological facies being petrophysically meaningful through porosity, permeability, P_c and K_r .

To achieve this point, petrophysical properties have to rely on 3D-predictive variables (such as Geological Facies) depending on a quantification of statistical correspondances between Geological Facies (including sedimentological and diagenetical patterns) and Petrophysical Groups (rock units with homogeneous petrophysical behavior).

Carbonates rocks require a specific approach compared to clastic ones due to a higher level of complexity (facies heterogeneity, early and/or late diagenesis, pore topology, wettability changes).

A specific workflow based on 30 years of experience on world wide carbonate reservoirs has been developed, supported by in-house or commercial softwares. As a result of more than 10 years of R&D effort on sedimentology, diagenesis and petrophysical synthesis, relying on numerous case studies (REBELLE *et al.*, 2000; REBELLE & AL NUAIMI, 2004; REBELLE *et al.*, 2005; REBELLE & UMBHAUER, 2008; UMBHAUER *et al.*, 2008), this resulting workflow reflects an integrated approach of different specialities as illustrated on Figure 1.

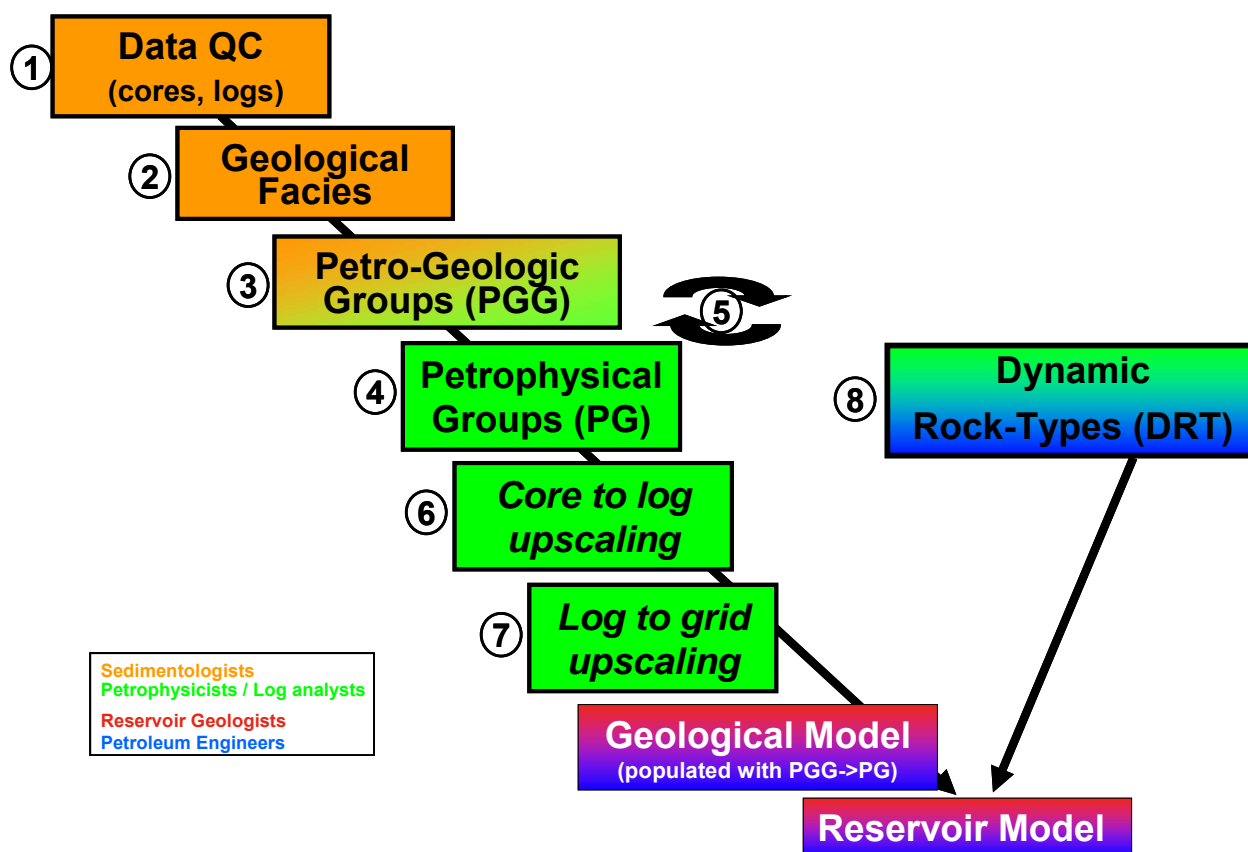


Figure 1 – Rock-Typing workflow displaying the 8 steps detailed in the present paper

1 - Data QC

Core and log quality control are the critical first steps of any rock-typing process. This step is generally highly time consuming but bypassing would constitute a strong prejudice to the whole rock-typing process.

11 - Core data

Core data could be sources of many biases or even errors.

Representativity of a core according to the stratigraphical position along a well should be analyzed to account for burial trend, structural position or location within a HRSS (High Resolution Sequence Stratigraphy) framework and stratigraphical local (even regional) sedimentological or diagenetical variations.

Plug sampling then orientation should be anticipated and should characterize all available facies with, when possible, a comparable amount of samples per facies, including non-reservoir facies. This sampling should be driven by core logs, core description and/or CT Scans.

Errors could also come up during sample coring, plugging and cleaning preparation, leading to the alteration of in situ conditions, or during the measurement of any physical properties (wrong or inadequate process or equipment). Crossing results from different sources is a good way to ensure data consistency: comparison of solid density calculated from XRD quantitative analysis and solid density measured on CCA (Conventional Core Analysis), shale typing from XRD, occurrence of heavy minerals or light components.

Finally, some corrections have to be applied to CCA results like overburden factor, Klinkenberg effect (Kg_KL vs Kg for low permeable gas reservoirs, Kw vs Kg_KI for oil reservoir), impact of temperature when HP/HT conditions occur.

12 - Log data

Log data from a same field can originate from different runs, different vintages or even different companies.

A detailed quality control should help discarding any anomalous recordings. Once all validated logs have been selected, a specific processing phase, dedicated to electrofacies interpretation is definitely necessary before any interpretation.

According to TOTAL standards of procedures, logs have to be carefully cleaned of acquisition artifacts if necessary

and corrected from hydrocarbon content, compaction effect, and finally normalized, in order to maximize the lithological signal over the acquisition and environment noise. This pre-processing sequence is case dependent and requests significant log analyst skills.

2 - Geological Facies

Geological Facies are defined by macroscopic and microscopic studies, including recognition of depositional environment conditions and of diagenesis impact on original texture and pore network. Carbonate rocks pore networks can be characterized at macroscopic scale (core description) or micrometric to millimetric scale by thin sections study (cements, pore types), CT scan imaging (textural interpretation, density image based petrophysical log) and SEM imaging. The scale of pore network characterization is function of the scale of heterogeneity.

3 - Geological classification: Petro-Geological Groups (PGG)

The Petro-Geological Groups (PGG) are defined from core data (geological descriptions at all scale but calibrated on petrophysics) and specifically processed log data (porosity, density, sonic velocity, mineralogy). PGG integrate the petrophysical impact of core (Φ , K, ρ , Pc...) and logs (porosity, mineralogy) in the definition of geological classes. A large amount of parameters are taken into account for PGGs definition : depositional facies, texture, lithology (dolomite vs limestone), pore types, cement types (quality and percentage). Other parameters like stylolites, micro-fractures, oil stain, are in the same time calibrated on plug and log data. This results in a better integration between depositional facies, diagenetical overprint, porosity and lithology. This step can be considered as a pre rock typing phase.

To achieve this point, pre-processed logs are used. Core data (thin sections descriptions, plugs) have to be scaled up to wireline log scale using the Petrophysical Log approach (GREDER *et al.*, 1994). A Petrophysical Log is a continuous log of petrophysical data at core scale, allowing for the representativity of plug measurements (Figure 2) along the core section. In a second step, this high resolution log is upscaled towards wireline log data by using moving average algorithms, depending on the considered data.

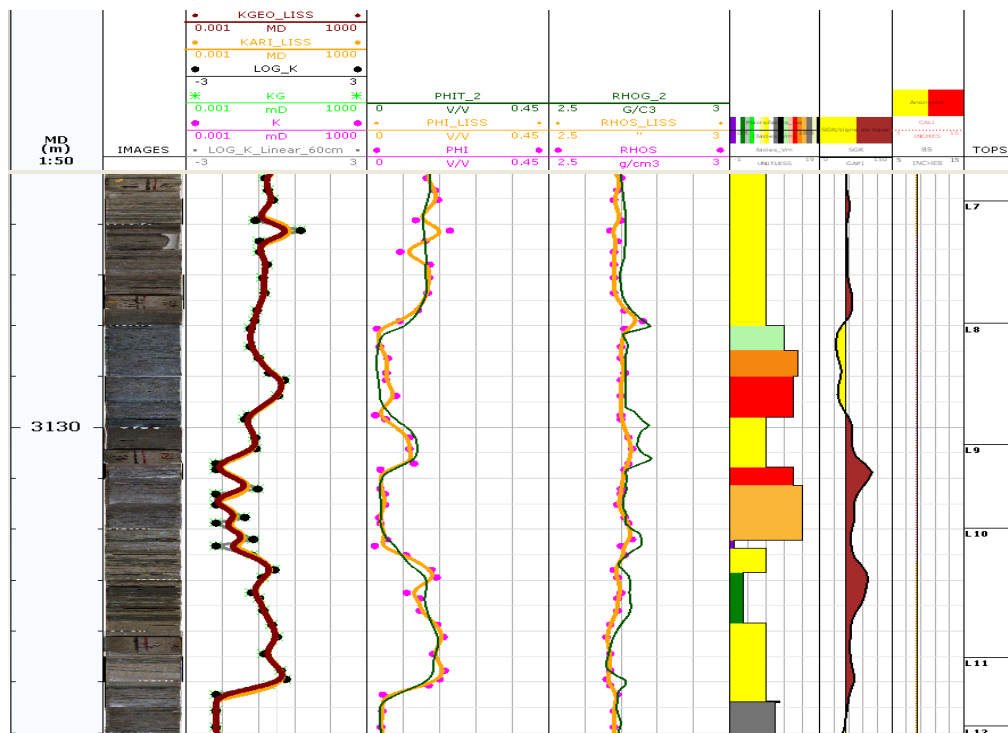


Figure 2 – Example of Petrophysical log of porosity (Track 4) and grain density (Track 5). (Track 6 : Macrofacies, Track 7 : GR and Track 8 : Caliper)

The impact of HRSS on facies distribution has to be properly investigated, which is of primary importance when the main heterogeneity is due to a stratigraphically linked diagenesis. As a consequence, an investigation based on data mining issued from different sequences or even half-sequences often leads to more evident clustering compared to the one issued from the whole reservoir.

The PGG interpretation (thin section + plug + log) is distributed along the core sections by means of the representativity concept based on core visual analysis, processed CT scan images (textural log) and log interpretation (high resolution imagery and conventional logs).

4 - Petrophysical clustering: Petrophysical Groups (PG)

In carbonate rocks, porosity and permeability are generally not significant enough to capture the petrophysical behavior. As a consequence, Petrophysical Groups (PG) are built using all available core data including CCA (porosity, permeability, grain density), Capillary Pressure data (Pc curve shape parameters calculated from hyperbolic tangent curve fit method, pore throat radius for mercury measurements) and/or any discriminating parameters brought to light during the sedimentological study (shape/size of dolomite crystals, pore geometry, pore size distribution, cement phases,...) providing they have been described on plugs or plug trims (Figure 3).

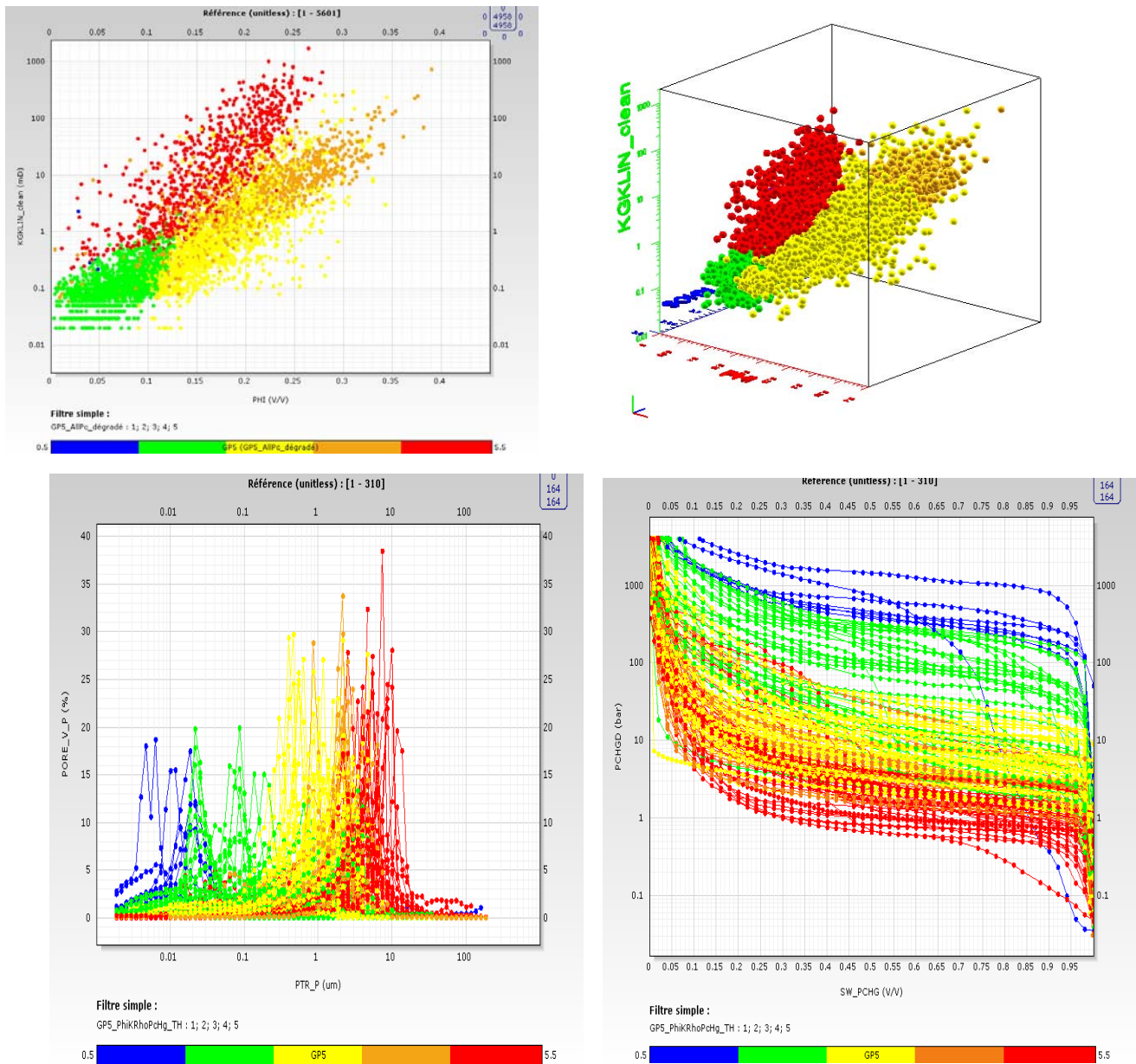


Figure 3 –Petrophysical Groups built from Φ , K, ρ_s , PTR and Pc curves parameters

5 - Relationship between Geology and Petrophysics

Petrophysical variables are not extrapolatable in 3D, due to the generally very large inter well spacing compared to the variogram range of petrophysical heterogeneity., Petrophysics has thus to be supported by geological concepts

related to geological classes defined on wells, seismic attributes, outcrop studies. The geological classes are expressed through Petro-Geological Groups based on logs and core data.

Moreover, an objective quantification of the static correspondences between Petrophysical Groups and Petro-Geological Groups throughout the cored intervals will avoid any subjectivity during the process and allow to estimate related uncertainties.

This correspondence is achieved through a contingency table (Figure 4). Several iterations between sedimentology, diagenesis and petrophysics are generally necessary to deliver the strongest possible contingency. Statistical coefficients like C Coefficient or V of Cramer can be used to quantify the strength of the contingency. These relationships should be as simple as possible (resulting into a limited number of classes) and should preserve the dynamic heterogeneity of the reservoir (preservation of the PG of the key facies ruling the flow pattern in the reservoir).

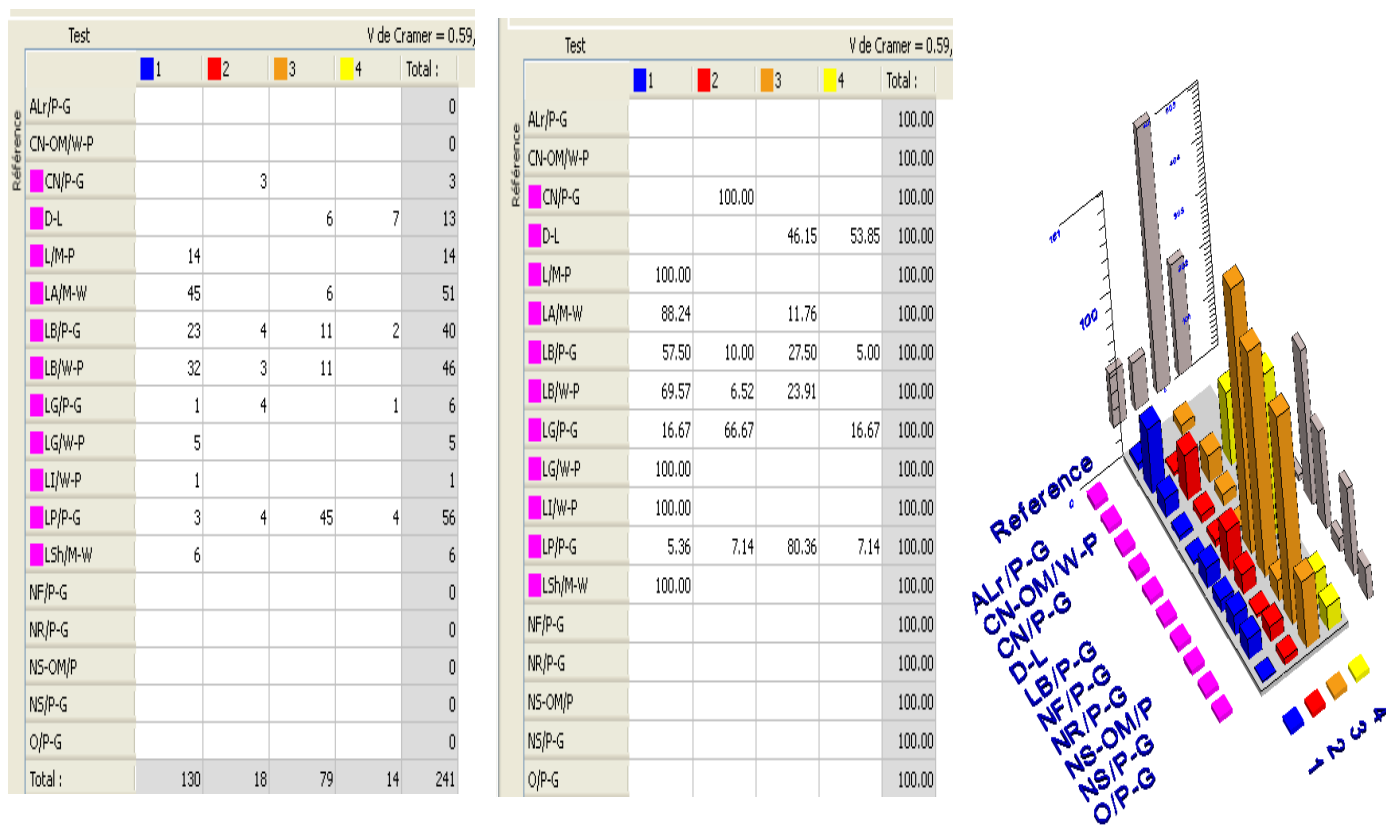


Figure 4 – Contingency table between Geological Facies (as reference) and Petrophysical Group (left : per sample number, centre : frequency per facies, right : 3D display of the contingency)

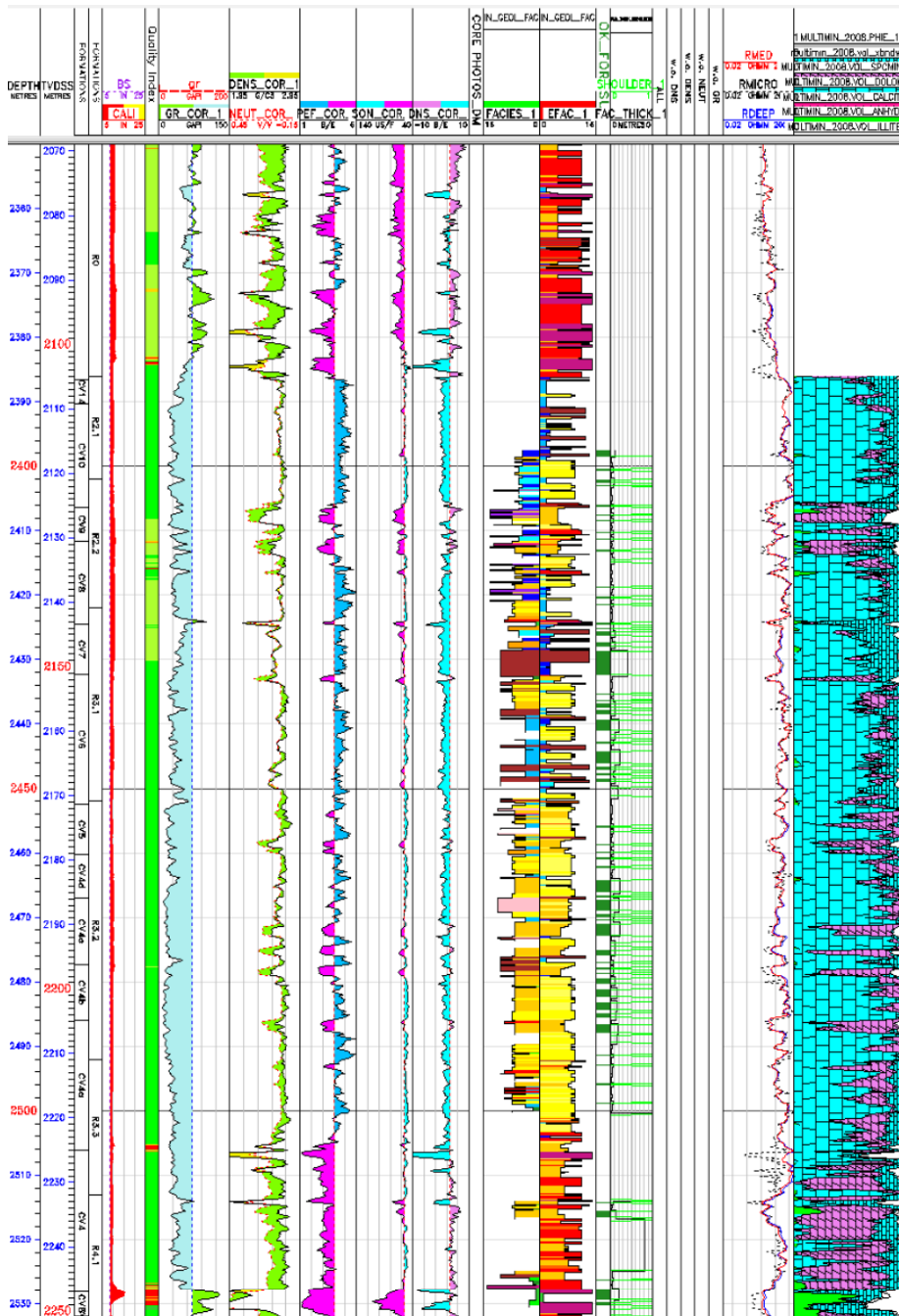
6 - Core to log upscaling and extrapolation outside cored areas

Electro-facies modeling of Petro-Geological Groups (PGG) is necessary to extend core-based interpretations outside cored areas and ultimately fill the geomodel.

Using pre-processed logs (Step 1.2), a supervised approach is performed using combined Multi Resolution Graph based Clustering (MRGC) and Kohonen Nearest Neighbours (KNN) techniques, with core sections PGG crenel logs as training sets (Figure 5). The consistency of the prediction is verified through a Similarity Threshold Model (STM). All developments can be found in YE & RABILLER (2000), VEILLERETTE *et al.* (1997).

Electro-facies should preserve the reservoir heterogeneity of core facies and be consistent with dynamic data inside/outside core domain (eg an electrofacies should not mix up hyperdrain core facies and lower permeability ones).

Moreover, blind-tests must be done in order to compare electro-facies and PGGs.



	NAME	COL	PAT
1	black shales radio	Green	Green
2	4-5-11 calc 0-5pu radio	Cyan	Cyan
3	5 calc 3-10pu radio bio	Blue	Blue
4	6-1 calc >10pu bio	Cyan	Cyan
5	7 dolo 15-25pu radio	Yellow	Yellow
6	7 dolo 10-20pu	Yellow	Yellow
7	7 dolo 5-10pu	Yellow	Yellow
8	7 dolo calc 2-8pu	Yellow	Yellow
9	7-8 calc dolo 0-5pu bio	Yellow	Yellow
10	8 calc 0-3pu bio	Yellow	Yellow
11	9-10 dolo calc 0-5pu radio	Red	Red
12	10 dolo 5-10pu shaly radio	Red	Red
13	11 calc 3-8pu bio	Brown	Brown
14	11 calc dolo 5-10pu radio	Brown	Brown
15	15 siltstone black shaly radio	Purple	Purple

Figure 5 – Example of supervised facies modeling using MRGC approach. Similarity Threshold Model (STM), is displayed under Track 6 as Quality Index.

7 - Log to grid upscaling

Upscaling is not limited to permeability. Petro-Geological Groups (PGG) and their associated PG, petrophysical distributions, saturation laws and cut-off values have also to be upscaled at geomodel/reservoir model scale. ω (the power averaging coefficient) is depending on the heterogeneity scale and distribution, and on the discretisation of the modeled domain (Figure 6). A diagnosis on ω value is provided by comparing test Kh and small scale core or log Kh.

Petrophysical and facies upscaling requires spatial analysis (H and V variogram ranges, grid cell geometry and aggregation rate knowledge). Upscaling results should be set against sedimentological, petrophysical and dynamic inputs (preservation of hyper drains, small scale saturation profile preservation, well KH, IP and Net Hydrocarbon thickness preservation).

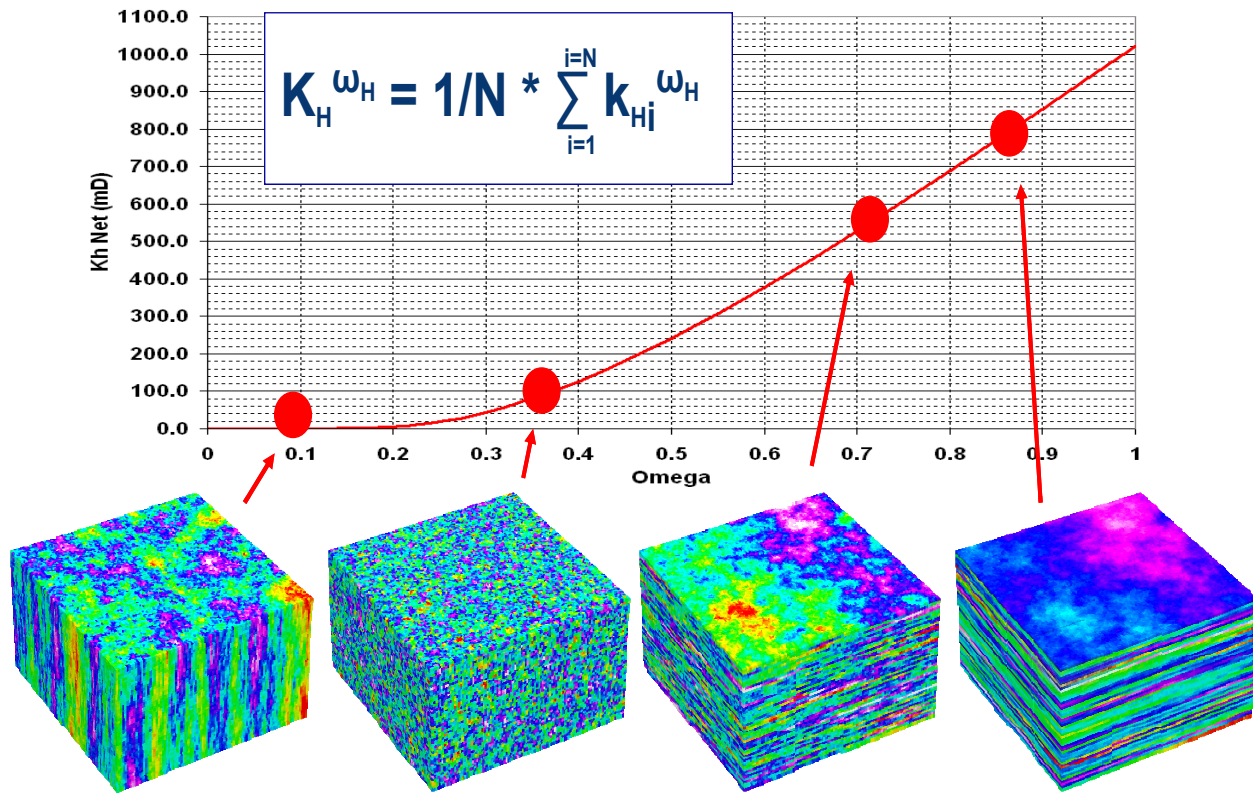


Figure 6 – Ω coefficient : Upscaling permeability power averaging for spherical flow.
 (with courtesy of G. MASSONNAT, TOTAL)

8 - Dynamic Rock-Types

Dynamic Rock-Types are defined as units of rock characterized by a similar range of pore geometry and wettability, resulting in a unique Kr-Sw relationship by rock-type.

For the same field, gas-oil relative permeability may largely be controlled by Petro-Geological Groups (PGG), whereas these same PGGs may fail to correctly represent water-oil relative permeability.

It is frequently assumed that Static Rock Types (represented by PGGs) are valid for assigning two-phase flow characteristics, such as relative permeability curves, to a reservoir, whatever the recovery process. This assumption is often incorrect. From a large number of core flood results, HAMON & BENNES (2004) have shown that the usual rock typing methods may not capture the actual variability of relative permeability curves. They also showed that multivariate descriptions, including petrophysical characteristics and wettability indicators, should be the basis for the generation of multiphase flow rock types.

Moreover, two-phase flow Rock-Typing is dependent on the recovery process. The application of the conventional static Rock-Typing approach to two-phase flow should be limited to flow mechanisms where a strong wetting preference exists (Figure 7).

Multivariate descriptions, including geological and petrophysical characteristics, and wettability indicators (*i.e.* height above contacts/FWL, for instance) aims at capturing most of the variability of Kr curves.

	Recovery Mechanism	Wettability	Kr
GAS FIELDS	Water invasion	Water wet	Kr ↔ Porous network
OIL FIELDS	Water injection	Mixed wet	Kr ↔/↗ Facies
	Gas injection	Low oil wet	Kr ↔ Facies
		High oil wet	Wettability ↔ Kr ↔ Facies
	WAG	Ongoing research in Heriott Watt University Based on physical micro-models Variability of Kr and Wettability	

Figure 7 – Possible links between Static Rock-Types (assigned by Facies or Porous network) and Dynamic Rock Types (assigned by Kr or Wettability) (by courtesy of G. HAMON, TOTAL)

Conclusions

Carbonate Rock-Typing studies should be adapted to data set nature and heterogeneity, and to the objectives of the reservoir study. The ultimate objective of reservoir flow simulation should be kept in mind to avoid excessively large numbers of rock-types and to allow spatial propagation within the geological model, through a robust relationship between geology and petrophysics.

Integration of all specialists input from the sedimentologist to the production geologist and the reservoir engineer is absolutely necessary to insure an efficient dynamic rock typing leading to a good representation of the reservoir production mechanisms, flow patterns and thus predictive profiles.

Rock typing studies in carbonate reservoirs request consistent and representative data base (cores and logs), and quite long acquisition, processing, and interpretation time. They should be as far as possible anticipated and carefully coordinated to ensure delivery of high quality, meaningful and usable results in time.

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