[PS]Integration of MICP Data with Logs, as a Means to Improve Reservoir and Seal Characterization*

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Abstract

The importance of MICP is widely recognized as a means to characterize the porous network of reservoir formations and to understand how it controls the fluids flow and its use for a quantitative evaluation of the sealing capacity of a rock. This poster proposes a flowchart for the integration of MICP data into multi-well projects at field or basin scale in order to characterize rock facies in terms of porous network and to model their sealing efficiency in terms of the maximum hydrocarbon column height needed to overcome the Capillary pressure forces. The modeling takes into account the type of Hydrocarbons and the pressure and temperature conditions prevailing during migration. The Purcell method is the core of the process, by which the pore throat size distribution (PSD) of a rock sample is derived from the MICP measurements; it is devoid of any user bias and does not requires any assumption about the distribution; its results can be confidently benchmarked against permeability measurements. The integration of PSD together with regularly sampled logs allows its prediction over the complete logged interval of any well, even the uncored ones. The predicted PSD is the foundation for modeling the sealing capacity of the varied rock facies; it is also an invaluable input for advanced facies characterization. A field example illustrates the flowchart of the process of MICP, how the resulting PSD is integrated with the logs, upscaled at log resolution and how the sealing efficiency is modelled. In order to evaluate the sealing potential of the rocks, it is critical to determine the pressure required to form a connecting filament of non-wetting fluid through the largest connected pore apertures of the rock. The objective of the method proposed here is to derive, from MICP drainage curves, the pore aperture at which porous network is fully connected and to predict it, at basin scale, over the entire logged (cored and uncored) intervals of a possibly very large number of wells. Sealing efficiency is the height of the Hc. column needed to overcome this pressure. The proposed methods are:

1. Loading and presenting MICP curves in the format of well logs. Performing QC and conformance correction.
2. Extracting the Pore Throat Size Distribution and the contribution to permeability of each class of pore size, by PURCELL method,
3. Extracting the critical pore aperture (and all other characteristics of Porous Network known to be derivable from MICP)
4. Integrating PSD with core measurements and log data and predicting the PSD over uncored intervals, by means of k-NN algorithm.
5. Upscaling, from plug scale to Log scale and Bed scale, the results of prediction
6. Simulating Fluid properties (interfacial tension and density) as a function of subsurface Pressure and temperature conditions.
7. Computing the height of the hydrocarbon column which may be trapped by a given rock facies.

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Objectives:

According to SCHOWALTER, WINLAND and PITTMAN, in order to evaluate the sealing potential of the rocks, it is critical "to determine the pressure required to form a connecting filament of non-wetting fluid through the largest connected pore apertures of the rock". The objective of the method proposed here is to derive, from MICP drainage curves, the pore aperture at which porous network is fully connected and to predict it, at basin scale, over the entire logged (cored and uncored) intervals of a possibly very large number of wells. Sealing efficiency is the height of the Hc. column needed to overcome this pressure.

Proposed flowchart:

1. Loading and presenting MICP curves in the format of well logs. Performing QC and conformance correction.
2. Extracting the Pore Throat Size Distribution and the contribution to permeability of each class of pore size, by PURCELL method,
3. Extracting the critical pore aperture (and all other characteristics of Porous Network known to be derivable from MICP)
4. Integrating PSD with core measurements and log data and predicting the PSD over uncored intervals, by means of k-NN algorithm.
5. Upscaling, from plug scale to Log scale and Bed scale, the results of prediction
6. Simulating Fluid properties (interfacial tension and density) as a function of subsurface Pressure and temperature conditions.
7. Computing the height of the hydrocarbon column which may be trapped by a given rock facies.

Why integration and interpretation of MICP are really needed?

➤ Of the 82 MICP samples on which is based the WINLAND equation (published by Kolodzie in 1980) relating Pore Throat Size to Porosity and Permeability, only 26 samples are carbonates: is such a small data set sufficient to confidently address the problem?
➤ The importance and the principles of the analysis of MICP curves are well exposed by the experimental work of previous workers:
  ➤ SWANSON (1977) established, that the position on the MICP curve that represents a continuous, well interconnected pore system through the rocks, is the apex of a log-log plot of Pc vs. Mercury saturation. (This point is often referred to as the apex of Thomeer's hyperbola).
  ➤ SCHOWALTER (1979) "*pointed out that **the important aspect for evaluating seals for traps is to determine the pressure required to form a connecting filament through the largest connected pore apertures of the rock**.*"
  ➤ WALLS and AMAEFULE (1985), KATZ and THOMPSON (1986), PITTMAN (1992), NOKKEN & HOOTON (2008) have proposed algorithmic methods to pick the position of this point on MICP curves (and derive permeability). Implementation of their method is illustrated on tracks 9, 10 & 11.
➤ **The shape of the Pore Throat Size Distribution provides invaluable insights about rock forming processes and fluid flow .**
➤ **Full Integration, by formatting MICP curves as logs, allows algorithmic processing therefore speed and efficiency in large multi-well projects.**

Extracting PSD and Critical Pore Aperture from MICP curves
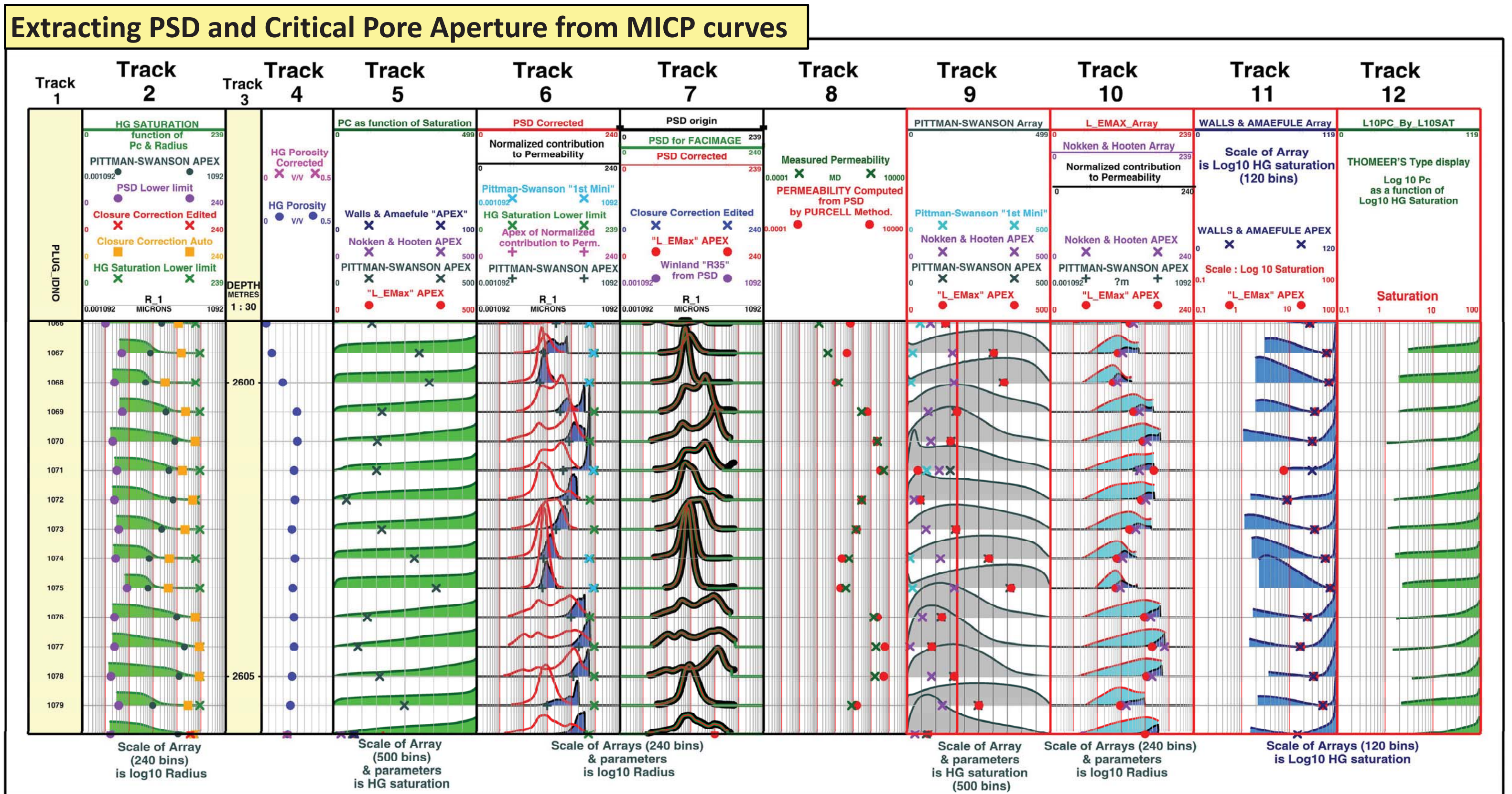
Why PURCELL method is preferred over parametrization methods to process MICP ?

➤ It is the most widely accepted method and the benchmark of all others methods.
➤ It does not require the user to assign a type to Pore Throat Distribution nor to specify a number of sub-populations in the distribution
➤ It derives Pore Throat Size distribution while retaining the full detail of MICP curves
➤ A standard format of "PSD" is most suitable for use of clustering and data prediction methods in large multi-wells projects.

Critical pore aperture shifts towards greater saturation with decreasing porosity

Purcell permeability is computed with a constant lithological factor

The 2 X-Plots above illustrate the consistency between the results obtained by means of varied methods to pick the critical pore aperture at which porous network is fully connected

The scattering increasing with pore aperture denotes greater textural variability in coarser facies.

The scattering increasing with decreasing porosity denotes greater textural variability and poorer sorting

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Migration and entrapment are controlled by the evolution of fluids properties through stratigraphic evolution.

**Evolution of Fluid parameters with Temperature and Pressure
Its effect on Hydrocarbon trapping.**

By default, the fluid parameters are derived from statistic of PVT data and literature (TENNY's nomographs published by SHOWALTER. "Mechanics of secondary hydrocarbon migration and entrapment"; AAPG Bulletin, v. 63, p. 723-760)

Application of Smith equation : $H = (PdB - PdR)/(0.4335*(Rho_W - Rho_{Hc}))$

A continuous profile of petrophysical parameters measured on Core Plugs is obtained by their prediction by means of k-NN method and using well logs as predictors
For a given depth/temperature hypothesis, the Sealing Efficiency of rocks, expressed in terms of Hc column height is derived from the continuous prediction of Pittman-Swanson or L-Emax apex, the corresponding Capillary pressure and the fluid density and interfacial tension.

Tracks 2 to 15 illustrate the various steps of extraction of static rock parameters and their prediction over the logged interval.
Tracks 6, 7, 10, & 11 illustrate the QC at the varied stage of prediction of core plugs and MICP curves.
Track 5 shows electrofacies log which is used to quantify calibration and understand stratigraphic and spatial distribution of properties
Tracks 16 illustrate the conversion of predicted Critical pore aperture into Capillary pressure for 2 scenarios of fluid flow
Tracks 18 & 19 illustrate fluid parameters and track 17 illustrate the Maximum Allowable oil Column Height for the 2 scenarios.