Mineralogical Model: The Basis for the Estimation of Accurate Cased Hole Petrophysical Properties in a Complex Environment. Case of Bajo Barreal Formation, Golfo San Jorge Basin, Argentina*

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Abstract

The estimation of the petrophysical properties for the formations belonging to the Golfo San Jorge Basin has been a challenge for geologist, petrophysicist, and engineers due its lithological complexity and variability of fluid properties. The challenge is even greater in cased holes, due to the limited number of logging measurements and evaluation techniques available in this environment. However, the advancement of the technology has enabled new evaluation workflows. The present work shows how a calibrated mineralogical model is the key to accurately compute the petrophysical properties such as clay volume, porosity, water saturation, and permeability through evaluation techniques not previously available due to the lack of quality through-casing measurements. The proposed workflow is based on logs that are available both in open and cased hole condition, like advanced induced gamma ray spectroscopy, sonic, and thermal neutron porosity logs. The first step of this methodology is to build a mineralogical model using the open hole logs and calibrate it to X-Ray diffraction (XRD) analysis on rock samples. The second step is to derive the matrix properties from the mineralogical model to correct the porosity logs for matrix effects. These porosities are then combined to correct for gas/light hydrocarbon effect using a similar principle to that of the Sonic-Magnetic Resonance technique (SMR); and to compute at the same time a gas volume. The final step consists in quantifying the liquid hydrocarbon volume out of the total organic carbon (TOC) fraction obtained from the spectroscopy log and combine it with the neutron-sonic gas to compute the total hydrocarbon saturation. Other open hole measurements, like magnetic resonance porosity, bulk density, and basic petrophysical core analysis, can also be used to calibrate and quality control the petrophysical model based on spectroscopy, thermal neutron, and sonic logs. This model can then be applied to spectroscopy, neutron, and sonic logs acquired in cased hole. This work describes the workflow, the applied methodologies and actual examples that illustrate the effectiveness of this quantitative approach and its applicability in open and cased wells.

References Cited

Cao Minh, C., G. Gubelin, R. Ramamoorthy, and S. McGeoch, 1999, Sonic-Magnetic Resonance Method: A Sourceless Porosity Evaluation in Gas-Bearing Reservoirs: Society of Petroleum Engineers, SPE Annual Technical Conference and Exhibition, 3-6 October, Houston, TX, SPE-

56767-MS, 13 p. doi.org/10.2118/56767-MS

Craddock, P., S. Herron, R. Badry, L. Swager, J. Grau, J. Horkowitz, and D. Rose, 2013, Hydrocarbon Saturation from Total Organic Carbon Logs Derived from Inelastic and Capture Nuclear Spectroscopy: Society of Petroleum Engineers, SPE Annual Technical Conference and Exhibition, 30 September – 2 October, New Orleans, LA, SPE 166297, 14 p. doi.10.2118/166297-MS

Herron, M.M., 1987, Estimating the Intrinsic Permeability of Clastic Sediments from Geochemical Data: Transactions, SPWLA 28th Annual Logging Symposium, 1987 29 June-2 July, London, England, SPWLA-1987-HH, 23 p.

Herron, S.L., 1987, A Total Organic Carbon Log for Source Rock Evaluation: The Log Analyst, v. 28/6, p. 520-527.

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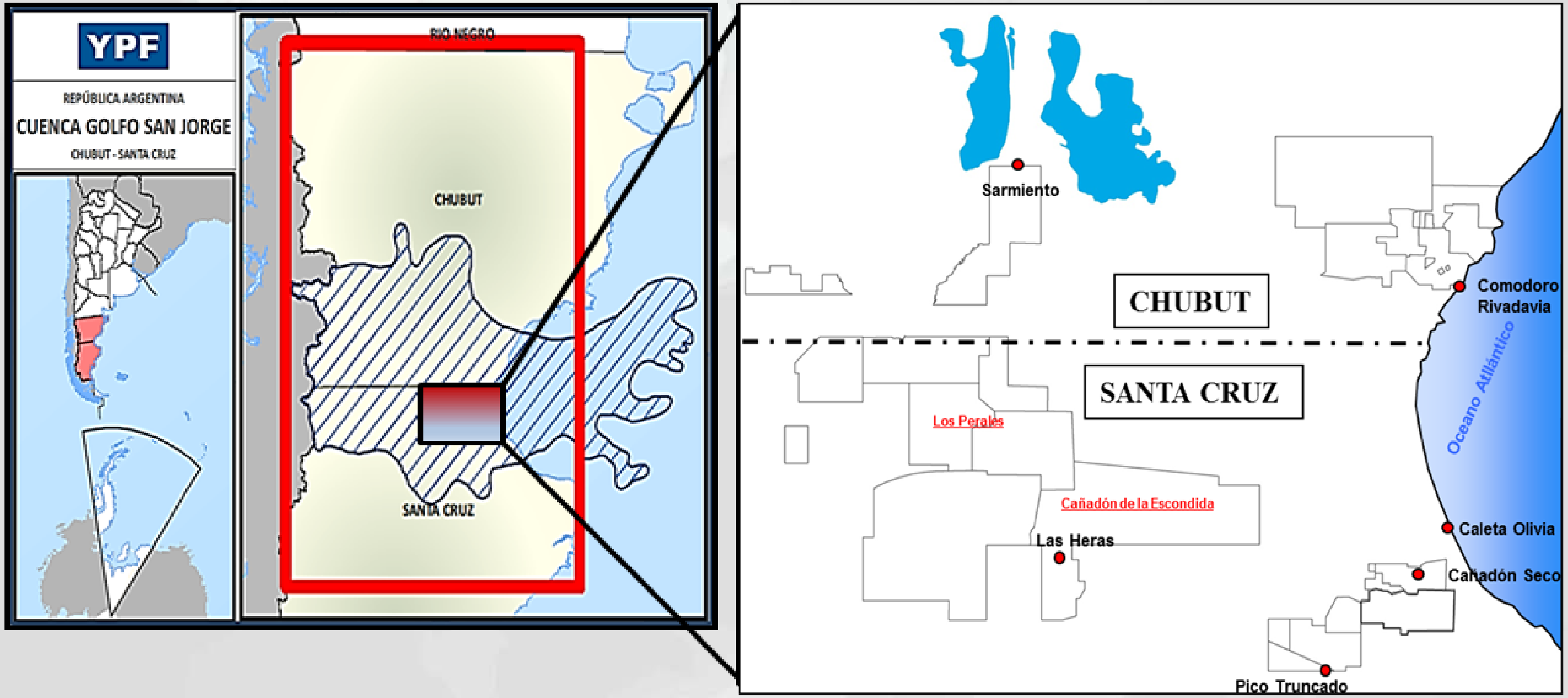
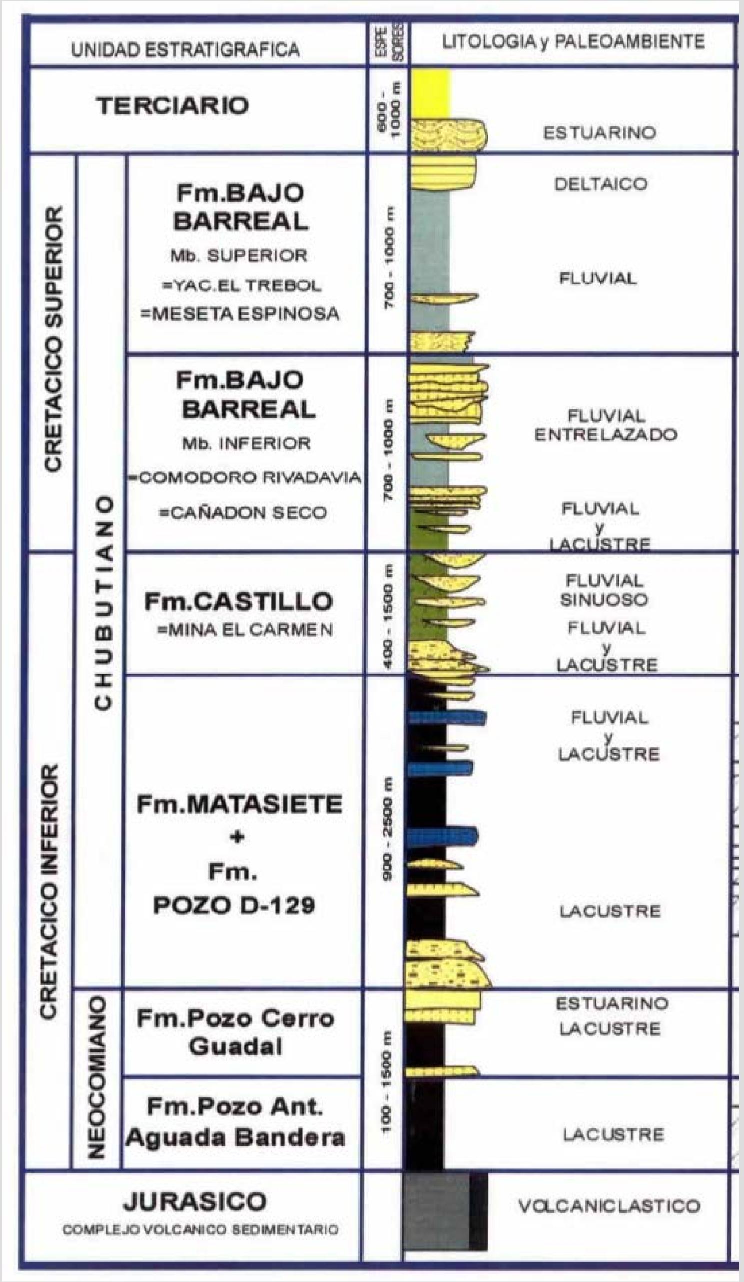
Outline

- Introduction
- A single general cased hole workflow
  - Mineral model calibration, the first step
  - Matrix properties computation, the second step
  - Porosity correction, the third step
  - Fluid saturations and permeability, the fourth step
- Results (Cases in different fields)
- Conclusions

San Jorge basin location and stratigraphy

Area: 200,000 km^2
Oil production: ~250,000 bbl/d
Exploration 1907, Production 1920’s





San Jorge basin challenges

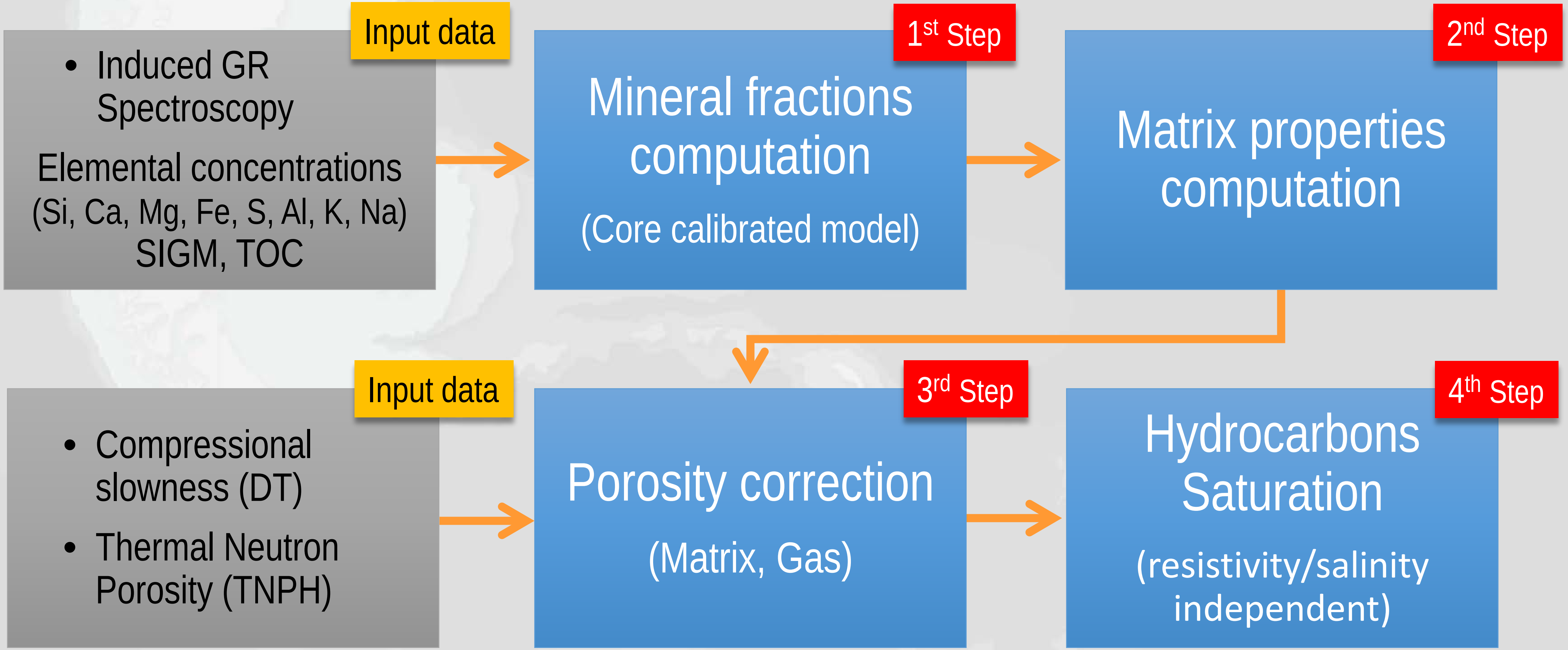
- Difficult drilling environment: long intervals with multiple stacked sands, swelling shales, depleted zones (mud loses, increased sticking risks).
- Logging operations can extend for several days if tools cannot reach TD and wiper trips are required (Efficiency ↓).
- Efficiency is a must for commercial viability. New well construction practices include the Casing Drilling technique, where cased hole log evaluation is the only option.
- Complex petrophysics: while open hole evaluation is difficult, standard cased hole evaluation is even more challenging.

Bajo Barreal reservoirs characteristics

- Multiple sands, 2 to 10 m thick, stacked over long intervals (typically > 1000 m, most wells are vertical)
- Porosity: 16 – 30%, Kgas: 50 – 2000 mD, oil API range: 15 – 30
- Complex mineralogy (quartz, feldspars, clays, tuffs, volcanic lithics)
- Low and variable formation water salinity (< 20 ppk NaCl)
- Conductive minerals (clays), fined grained sands (high Swirr)
- Thick mudcakes, deep mud filtrate invasion

Challenges

A single general evaluation workflow*



* Primarily designed for CH evaluation, but also applicable in the OH environment

Mineral model, 1st step

Elements to minerals, two possible solutions:

1. Use a simultaneous equation solver, with an **inversion** that minimizes the difference between the measured and reconstructed elements from the computed mineral fractions.

$$E = MC$$

E = elements vs. depth matrix
M = minerals vs. depth matrix
C = elemental concentration endpoints for each mineral

2. Create a **correlation matrix** between elements and minerals. The minerals are computed directly without an inversion.

$$M = EX$$

E = elements vs. depth matrix
M = minerals vs. depth matrix
X = correlation matrix between elements and minerals

Mineral model, 1st step

- Default coefficients exist for the end-points C matrix, and there are some global models/correlations for the X matrix, but they can be "optimized" locally with XRF (elements) and XRD/FTIR (minerals) core and/or cuttings data.
- *E* and *M* are known, C and *X* can be computed/optimized

$$E = MC \qquad M = EX$$

- Mathematically it can be solved as:

$$C = (M^t M)^{-1} M^t E$$

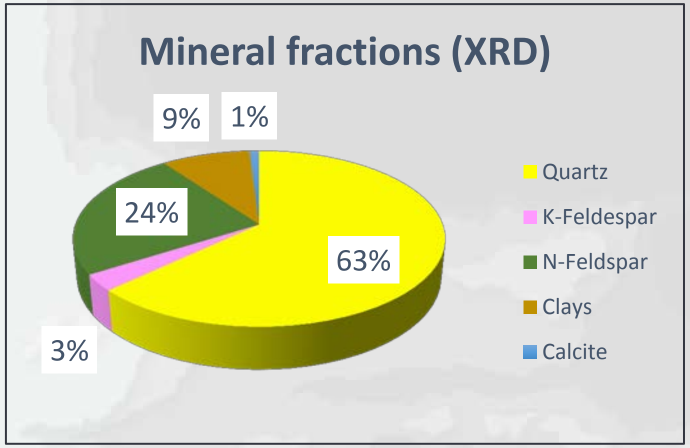
Optimize the end-points to use in the inversion

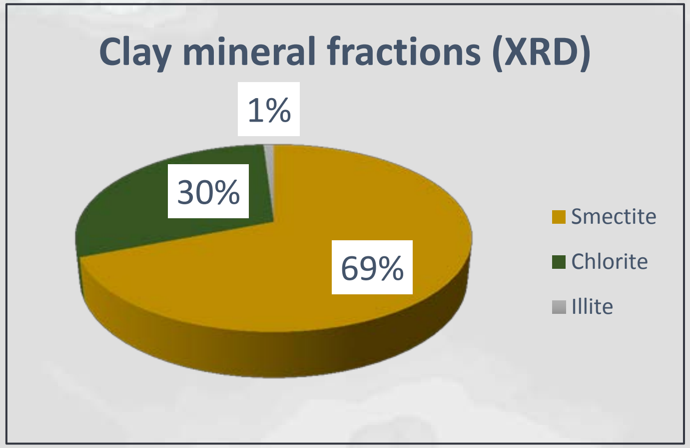
$$X = (E^t E)^{-1} E^t M$$

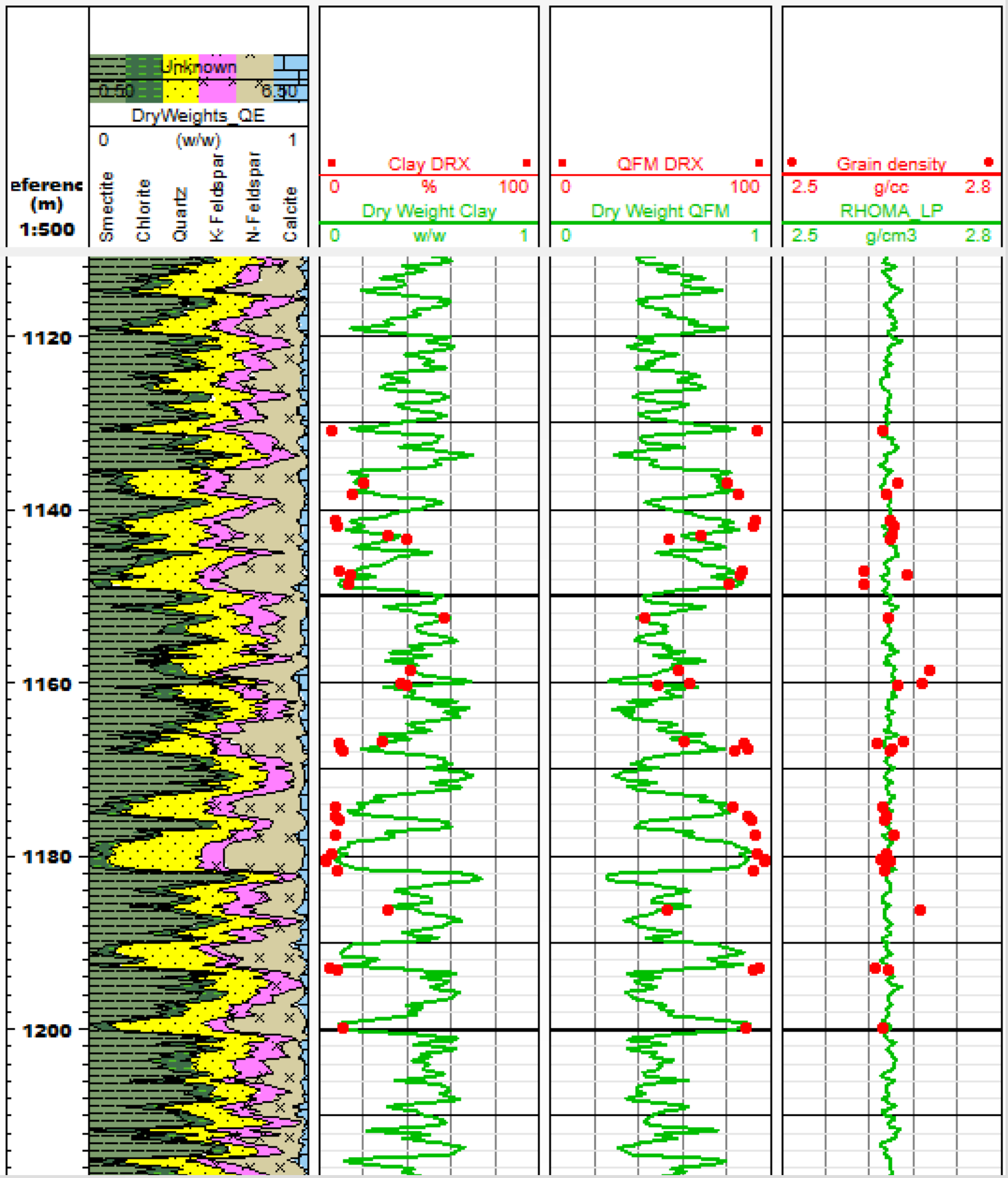
Optimize correlation coefficients

Mineral model calibration, 1st step

- Based on the available X-Ray Diffraction (XRD) core data.
- The advanced induced GR spectroscopy provides the elemental concentrations used to build the mineralogical model.
- The computation of the mineralogy from elemental concentrations is done through a simultaneous equation solver program with optimized end-points.



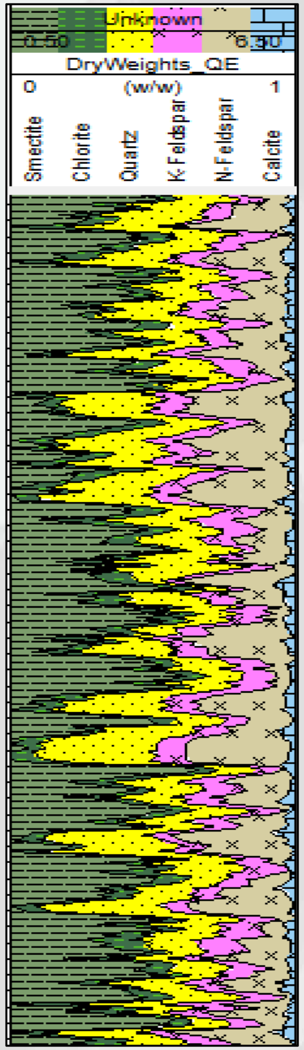




Matrix properties computation, 2nd step

The main interest of computing the matrix properties is to remove the matrix effect from the sonic and thermal neutron porosity logs.

Min. Model



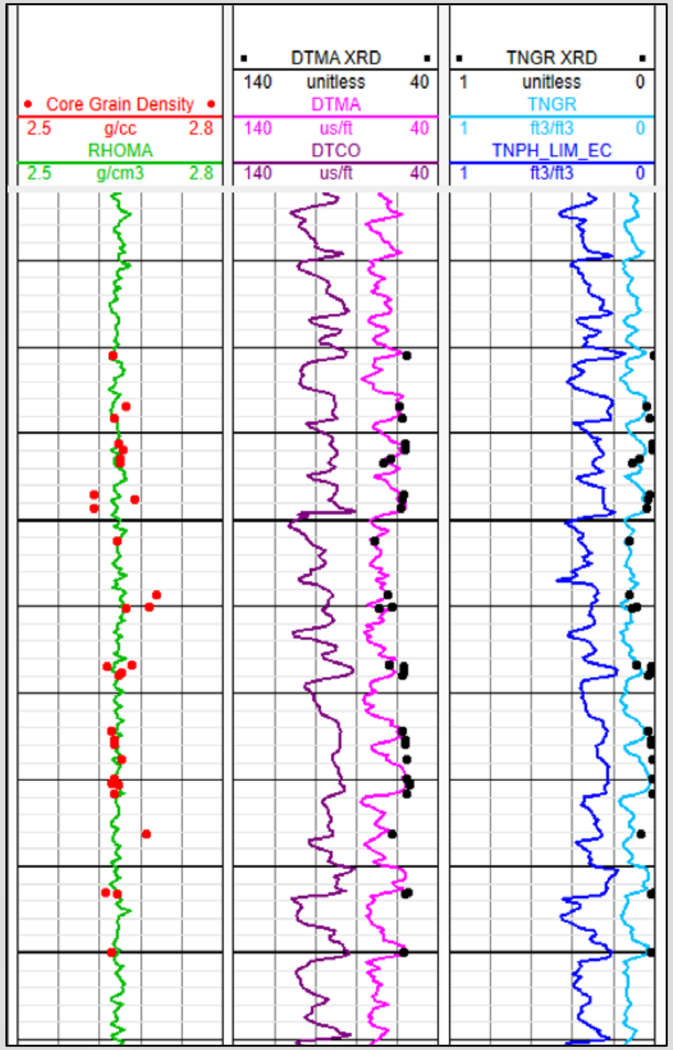
Matrix properties calculation

$$Rho_{ma} = \frac{\Sigma_i DWM_i}{\Sigma_i \frac{DWM_i}{RHM_i}}$$

$$DTMA = \frac{\Sigma_i \frac{DWM_i}{RHM_i} DTM_i}{\Sigma_i \frac{DWM_i}{RHM_i}}$$

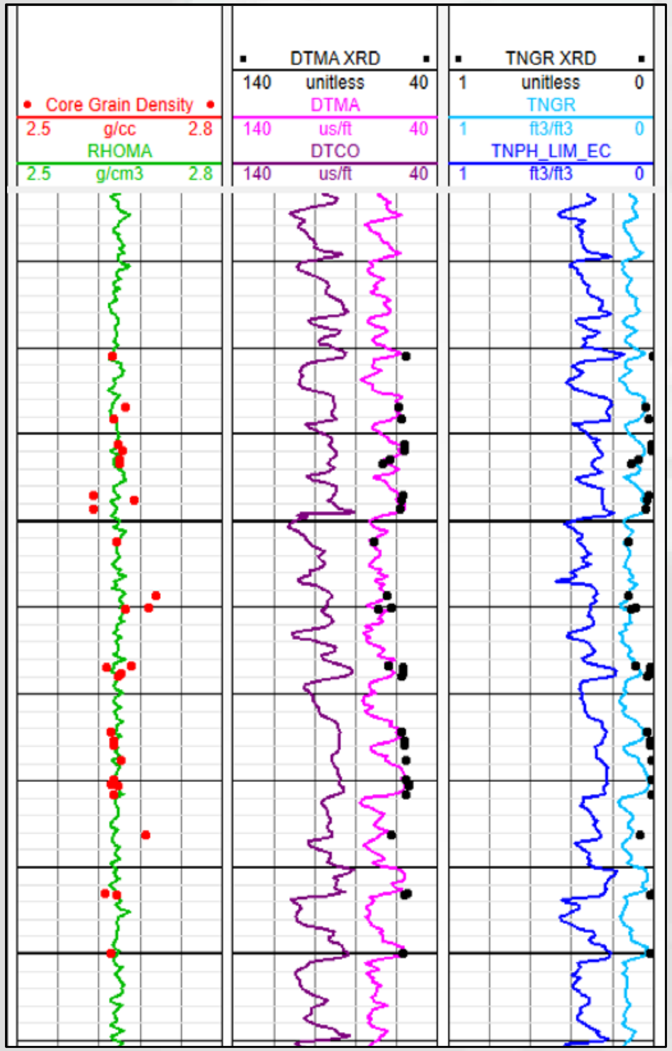
$$TNGR_{LIM} = \frac{\Sigma_i \frac{DWM_i}{RHM_i} TNM_i}{\Sigma_i \frac{DWM_i}{RHM_i}}$$

Computed matrix properties



Porosity correction, 3rd step

Computed matrix properties



Porosity correction computation

$$TNPH_{MC} = TNPH_{LIM} - TNGR_{LIM}$$

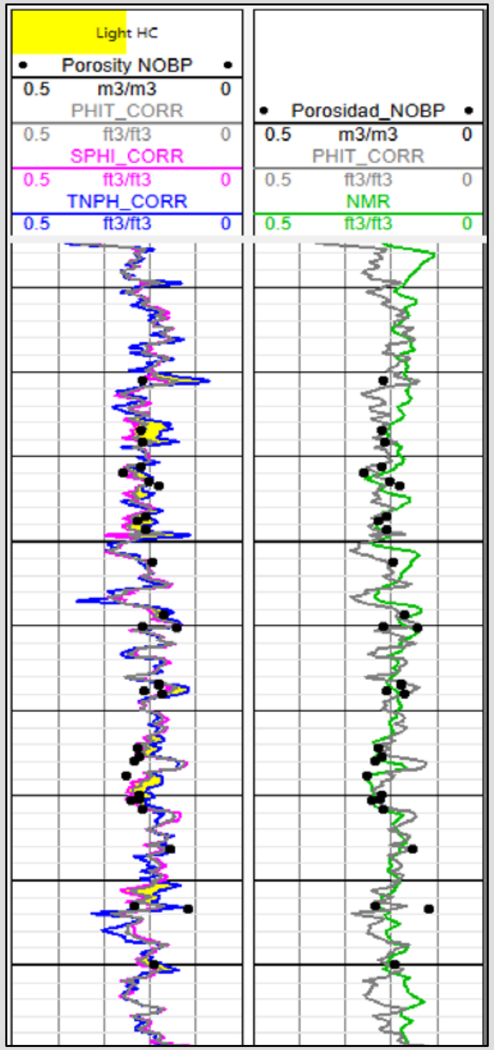
$$SPHI_{MC} = 1 - C - \sqrt{C^2 - \frac{DTMA}{\Delta t_f}} + \frac{DTMA}{\Delta t_l}$$

$$C = \frac{DTMA}{2 \cdot \Delta t_f}$$

$$\phi_{t\,corr} = \frac{SPHI_{MC} \cdot (HI_w - HI_g) + TNPH_{MC} \cdot \lambda}{(HI_w - HIg) + \lambda \cdot HI_w}$$

$$\lambda = \frac{\Delta t_f - \Delta t_g}{DTMA - \Delta t_f}$$

Porosity corrected



Fluids saturation and permeability, 4th step

Oil and gas saturations are based on two methods with different physical principles.

Gas saturation is computed simultaneously with $PHIT_{corr}$ based on the SMR method (Cao Minh, 1999),

Oil saturation is assessed based on the TOC which is provided by the advanced induced GR spectroscopy tool (Craddock, 2013).

The **intrinsic permeability** estimation is based on an empirical model that relates the permeability to porosity using the mineralogy as input as well (Herron, 1987).

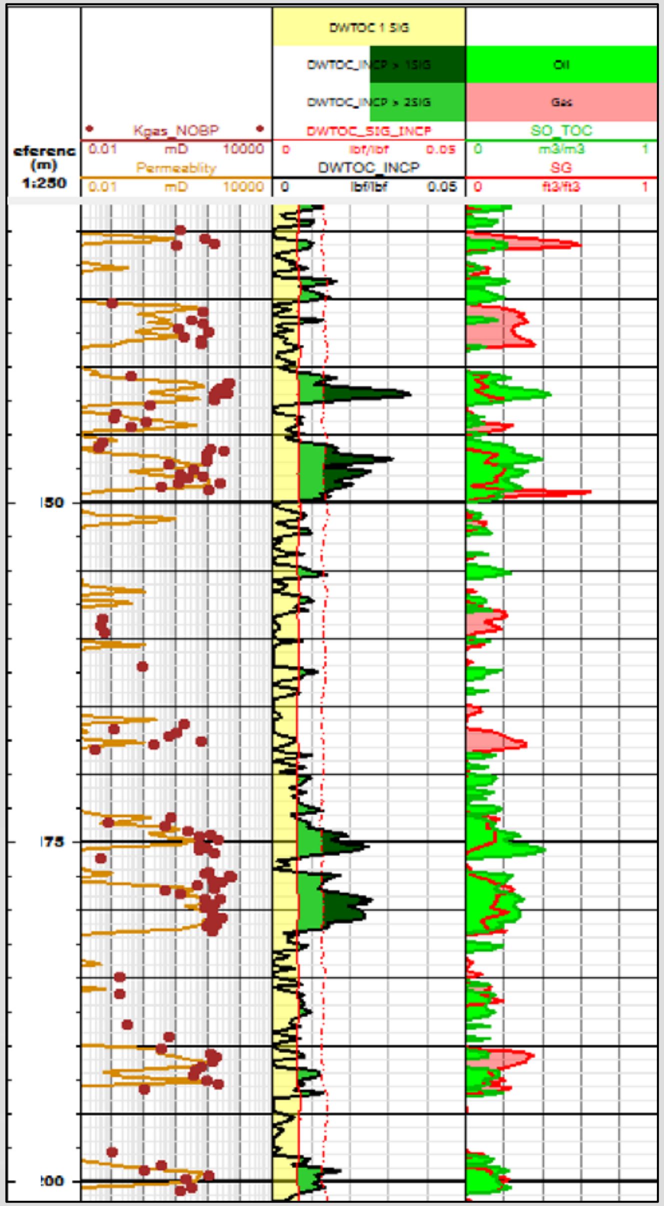
Fluids saturation

Gas saturation:

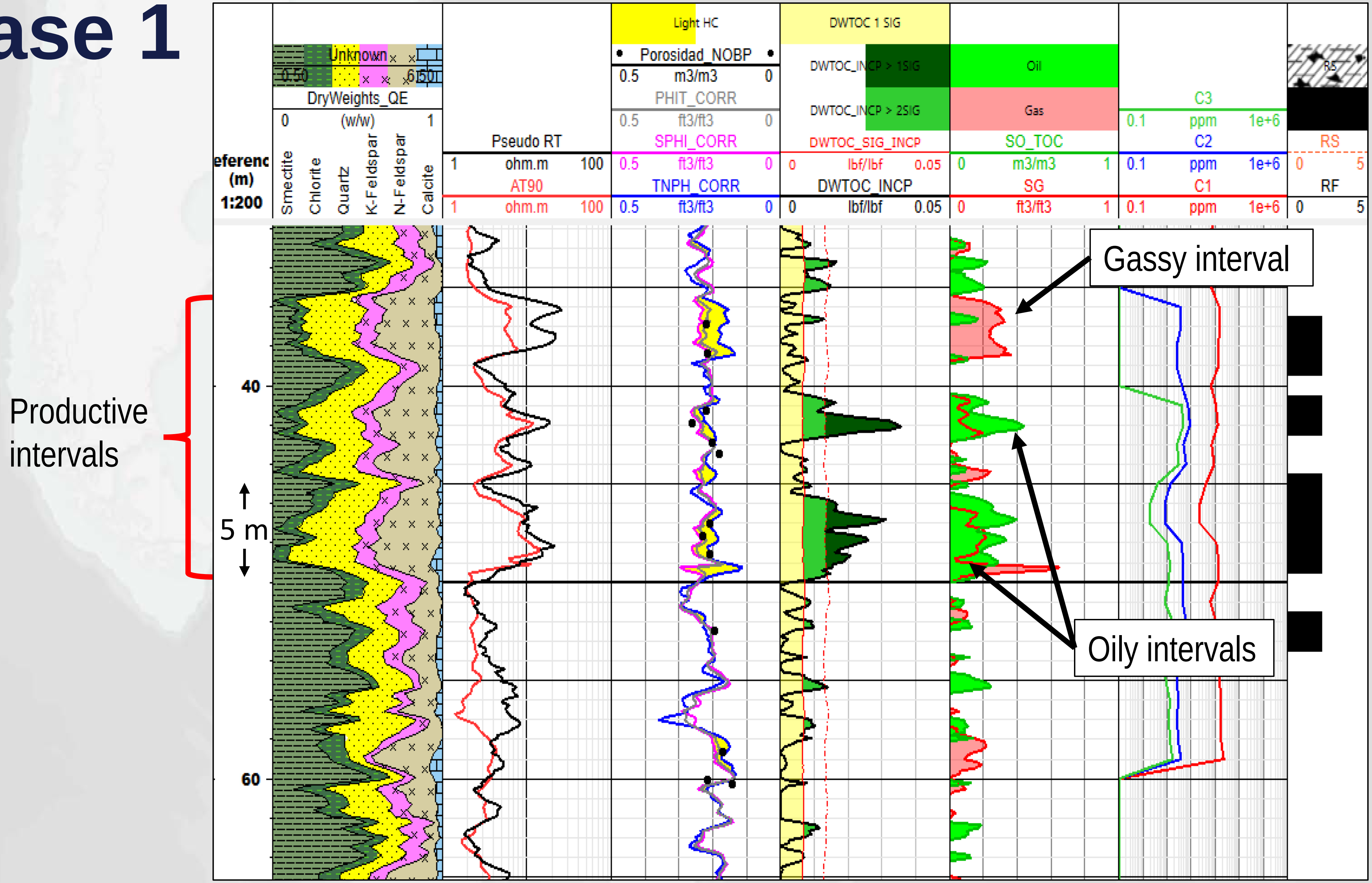
$$Sg = \frac{SPHI_{MC} - \dfrac{TNPH_{MC}}{HI_w}}{SPHI_{MC} \cdot \left(1 - \dfrac{HI_g}{HI_w}\right) + TNPH_{MC} \cdot \dfrac{\lambda}{HI_w}}$$

Oil saturation:

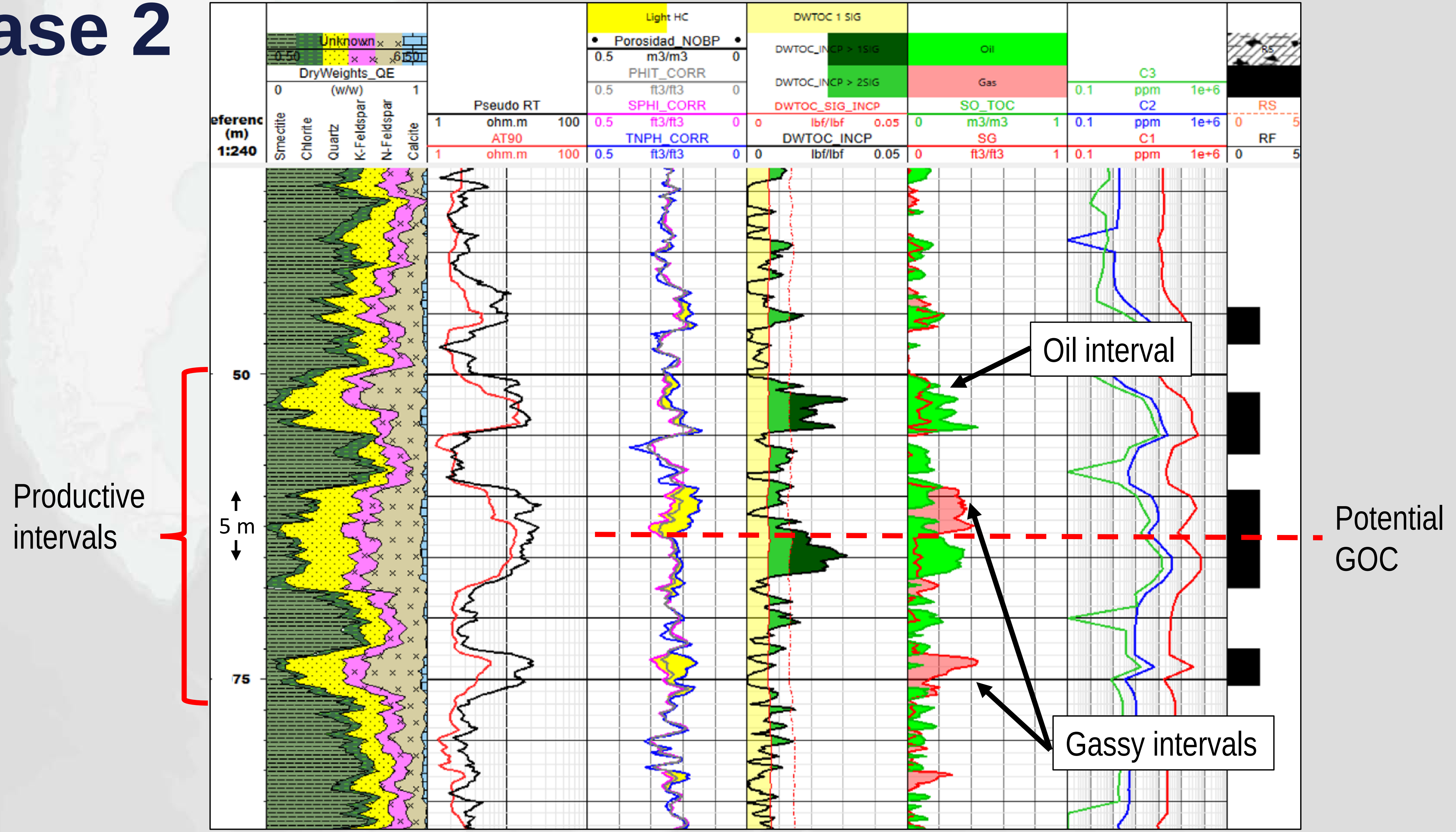
$$So = \frac{TOC \cdot Rho_{ma} \cdot (1 - \phi_{t\,corr})}{\chi_o \cdot \rho_o \cdot \phi_{t\,corr}}$$



Case 1


Productive intervals
5 m
40
60
eferenc (m)
1:200
Unknown
DryWeights_QE
0 (w/w) 1
Smectite
Chlorite
Quartz
K-Feldspar
N-Feldspar
Calcite
Pseudo RT
1 ohm.m 100
AT90
1 ohm.m 100
Light HC
Porosidad_NOBP
0.5 m3/m3 0
PHIT_CORR
0.5 ft3/ft3 0
SPHI_CORR
0.5 ft3/ft3 0
TNPH_CORR
0.5 ft3/ft3 0
DWTOC 1 SIG
DWTOC_INCP > 1SIG
DWTOC_INCP > 2SIG
DWTOC_SIG_INCP
0 lbf/lbf 0.05
DWTOC_INCP
0 lbf/lbf 0.05
Oil
Gas
SO_TOC
0 m3/m3 1
SG
0 ft3/ft3 1
C3
0.1 ppm 1e+6
C2
0.1 ppm 1e+6
C1
0.1 ppm 1e+6
RS
0 5
RF
0 5
Gassy interval
Oily intervals

Case 2


Productive intervals
5 m
Oil interval
Gassy intervals
Potential GOC
Pseudo RT
AT90
DryWeights_QE
Smectite
Chlorite
Quartz
K-Feldspar
N-Feldspar
Calcite
Light HC
Porosidad_NOBP
PHIT_CORR
SPHI_CORR
TNPH_CORR
DWTOC 1 SIG
DWTOC_SIG_INCP
DWTOC_INCP
Oil
Gas
SO_TOC
SG
C3
C2
C1
RS
RF
50
75

Conclusions

- We described a workflow that is based on an calibrated mineral model to compute accurate petrophysical properties, and it can be applied in the CH environment to the complex Sand Jorge basin reservoirs.
- The workflow is enabled by new advanced CH measurements, the spectroscopy in particular, that provides elemental concentrations for mineralogy and TOC for oil saturation.
- The methodology has been successfully applied to many wells, including 12 casing drilling wells completed during the current year to date.

Acknowledgements / Thank You / Questions

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