PETROPHYSICAL WELLBORE INVERSION

A NEW VALUE TO LOG DATA

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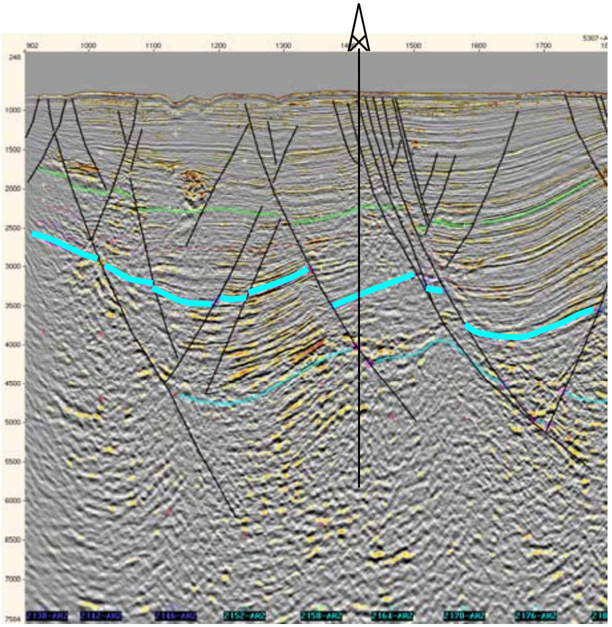
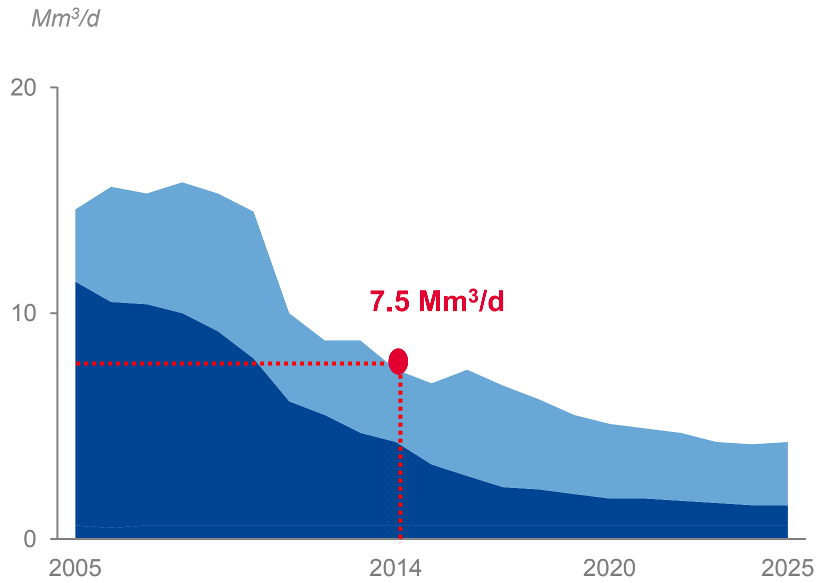
EXPLORATION-DEVELOPMENT IN ONE SLIDE

- **How to convert a seismic picture into a production profile ?**





- Requires dedicated data acquisitions…

- … to build a real **quantitative field dynamic scenario**

CONTENT

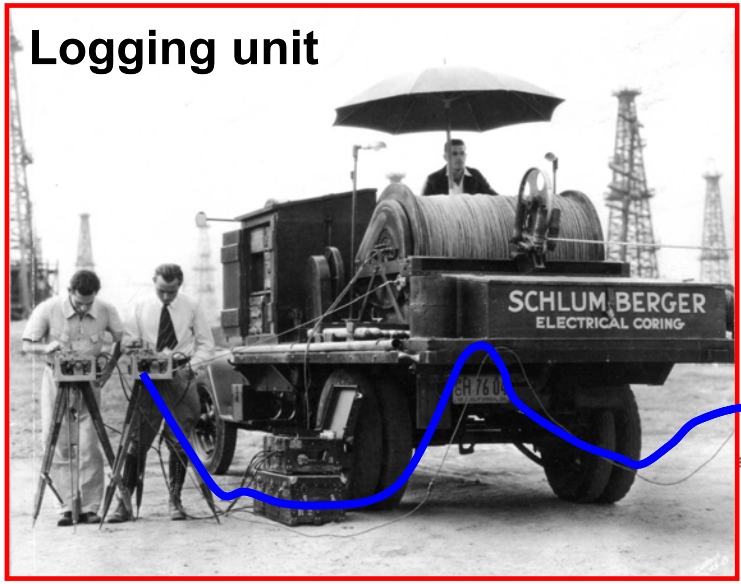
❶ • How to infer dynamic field properties ?

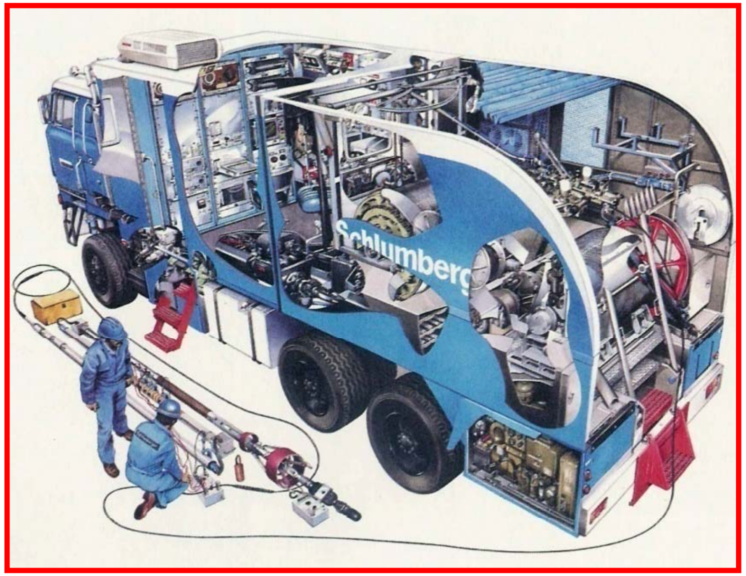
❷ • Logs simulation and inversion

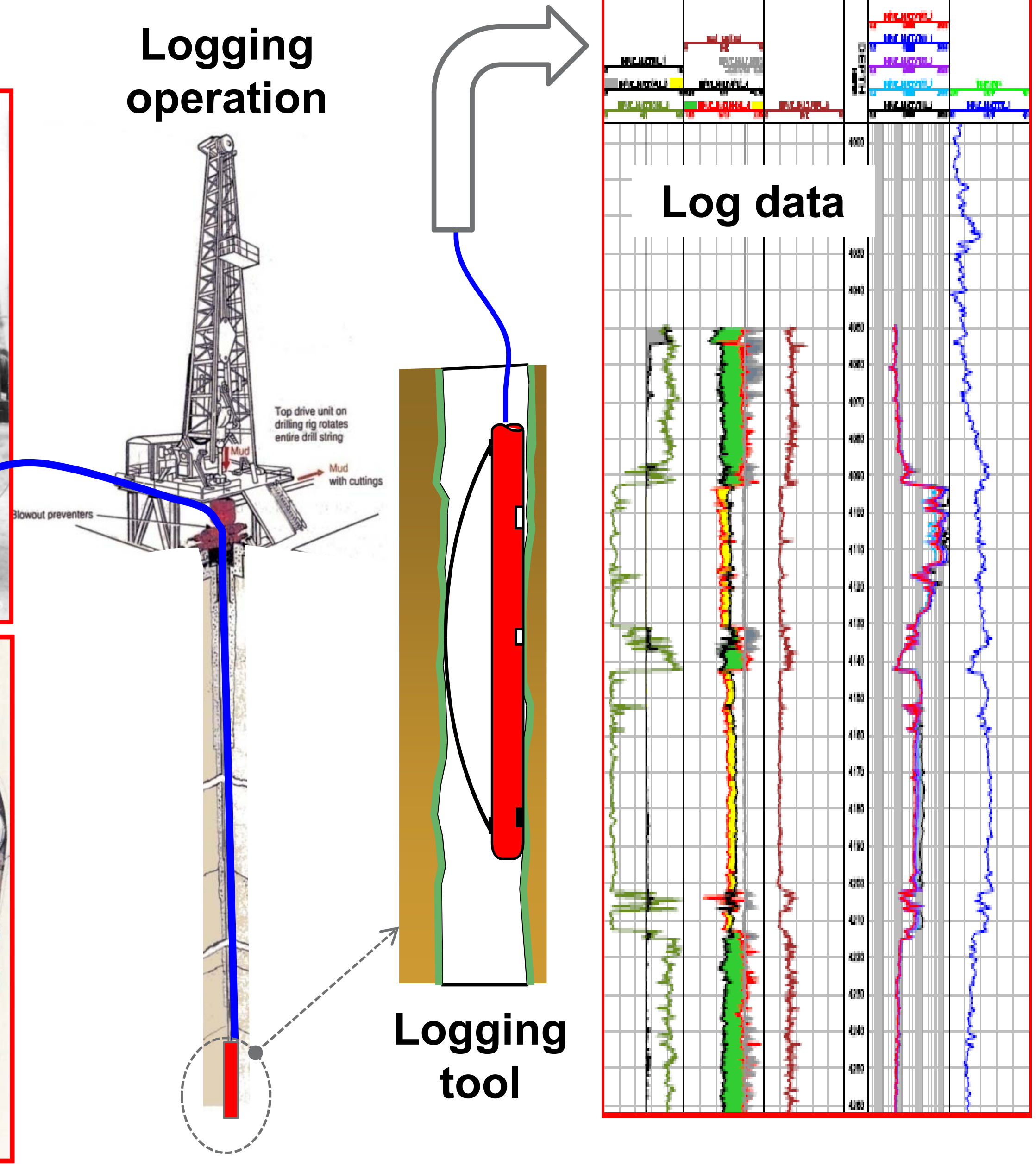
❸ • Well scale petrophysics: progress and first results

HOW TO INFER DYNAMIC FIELD PROPERTIES ?

WELL LOGGING





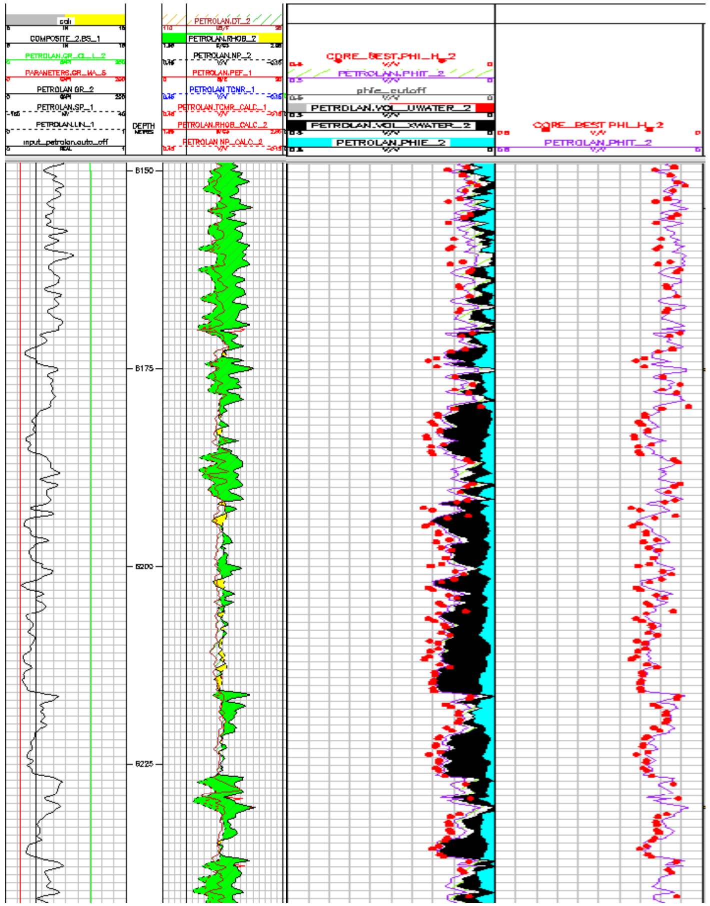


FORMATION CORING / DYNAMICS AT MACRO SCALE

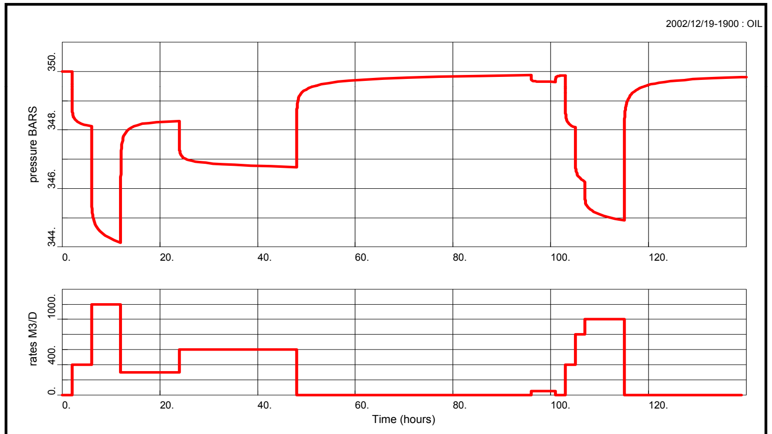
Core bit

Core

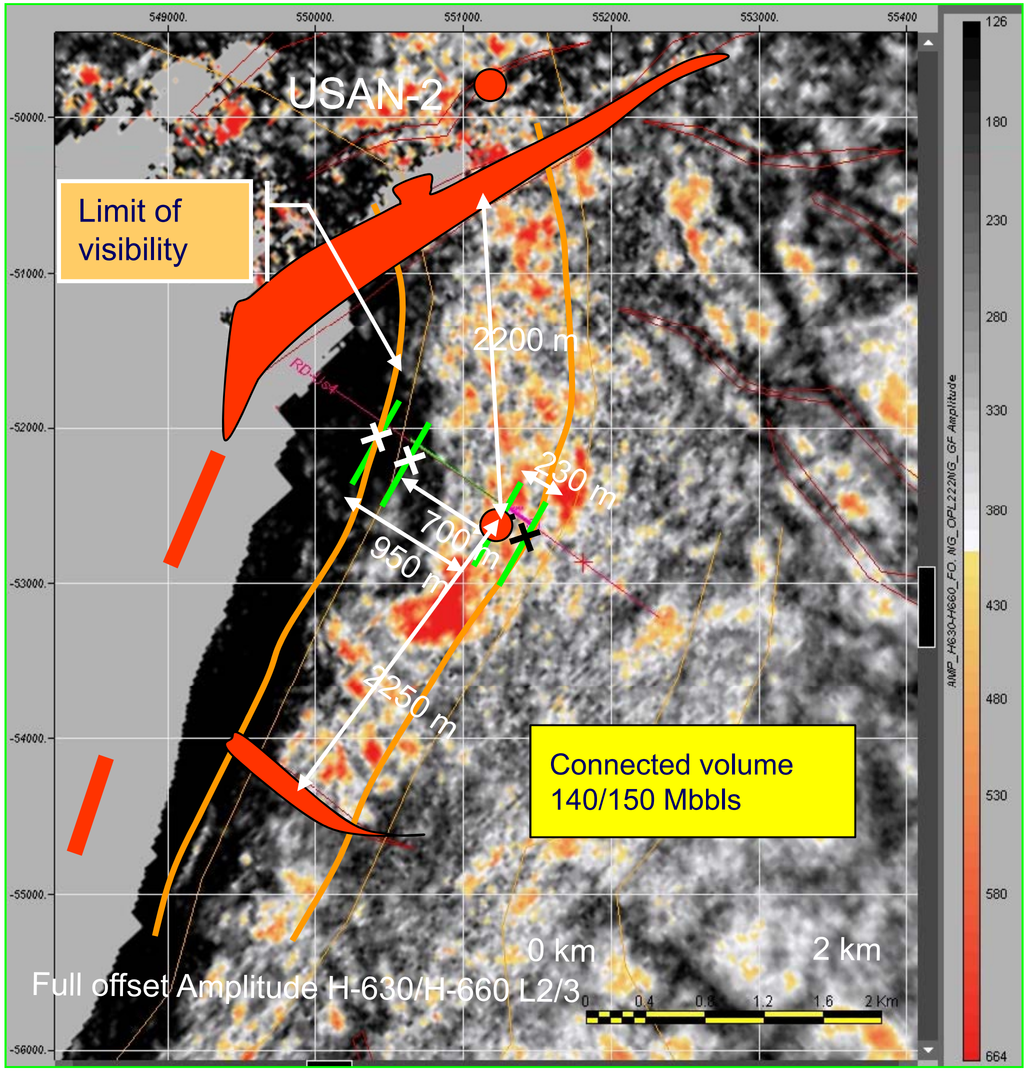
Core reults



WELL TESTING / DYNAMICS AT MEGA SCALE



DST Design



THE SCALE ISSUE

- The entire acquisition process is **synthetized in the end** at field scale via geological and reservoir models

- Data reconciliation is a **pure scaling issue**:
  - Micro-scale petrophysics (core data) vs. mega-scale dynamics (test data)
  - The intermediate scale is geology

  => What if complex heterogeneous reservoirs ?

- Well = an **intermediate scale** between the micro-scale (lab) and mega-scale (field)

- The « well » is for sure the **richest object in a field in terms of data**, but no data synthesis is really made at this scale

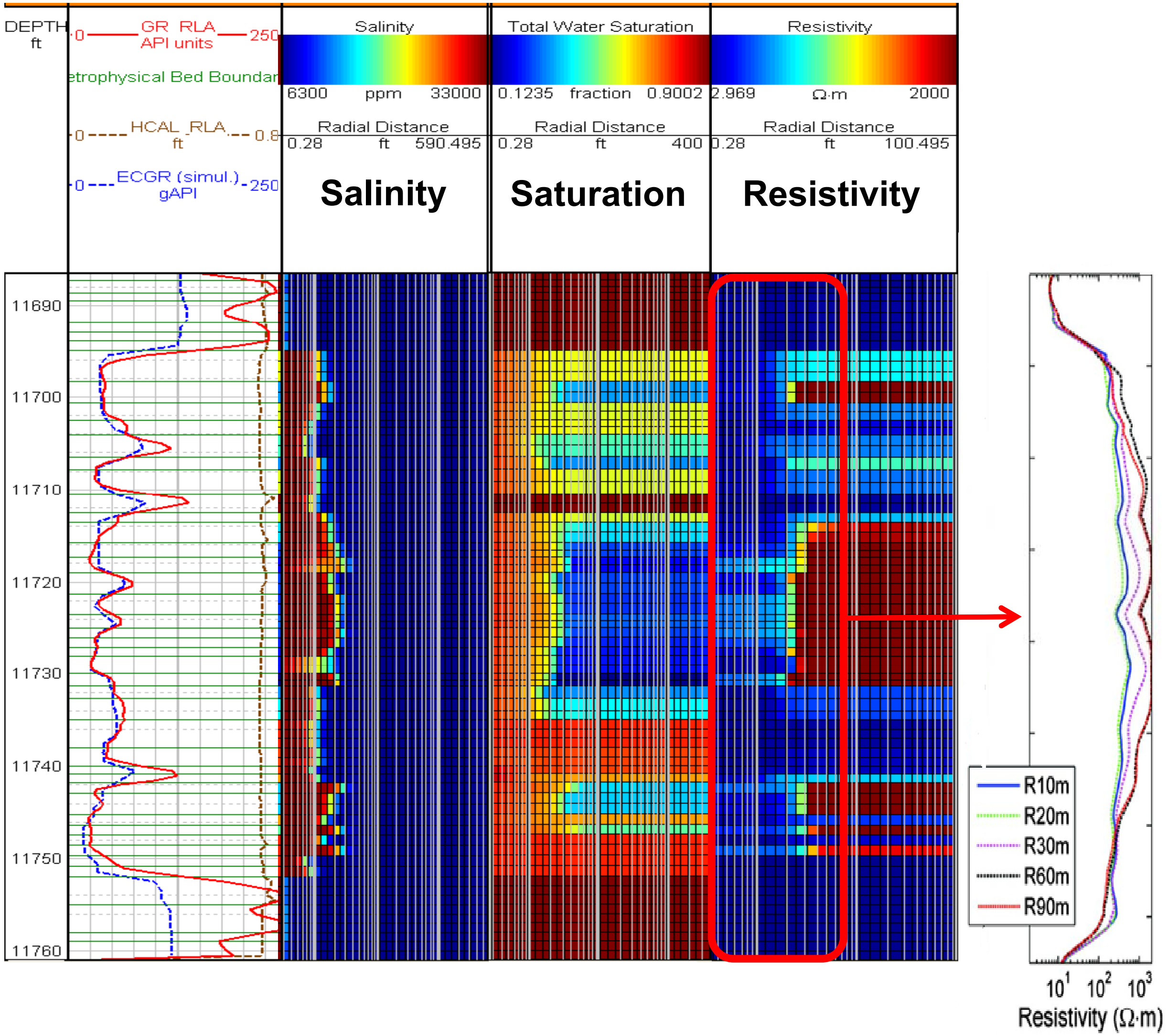
>> A STEP INTO WELL SCALE PETROPHYSICS

HOW TO INFER DYNAMIC FIELD PROPERTIES ?

LOGS SIMULATION AND INVERSION

OBJECTIVES, STAKES AND MEANS

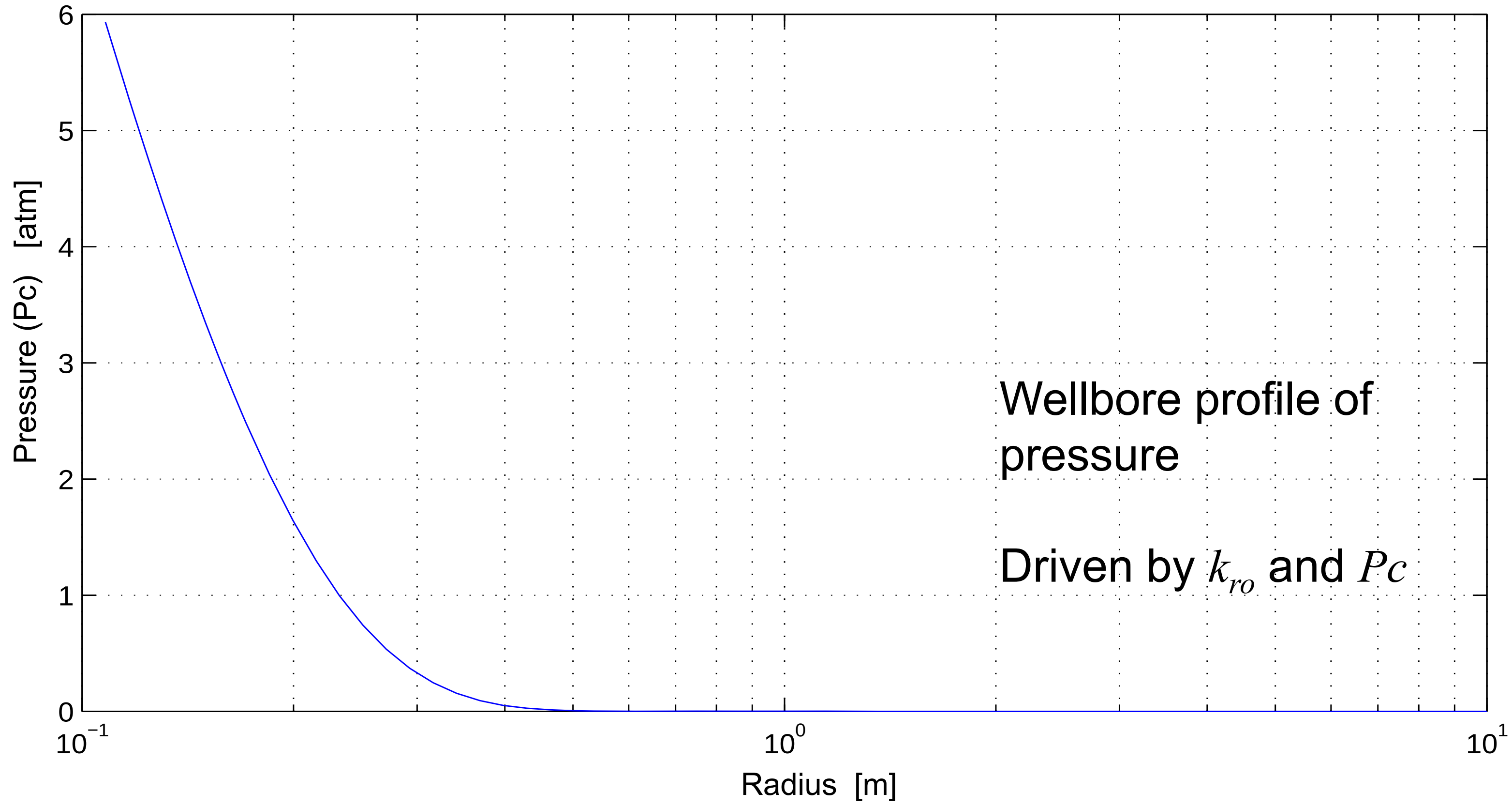
PHENOMENON OF MUD INVASION IN WELLBORE



- A **real in-situ dynamic** process occurs continuously in the near well bore
- **Logs are sensitive** to such fluid substitution, hence dynamics
- A **pure inverse problem**: Can we infer the dynamic properties by inverting log data ?

STEP 1: THE RADIAL PRESSURE PROFILE

Partial Differential Equation

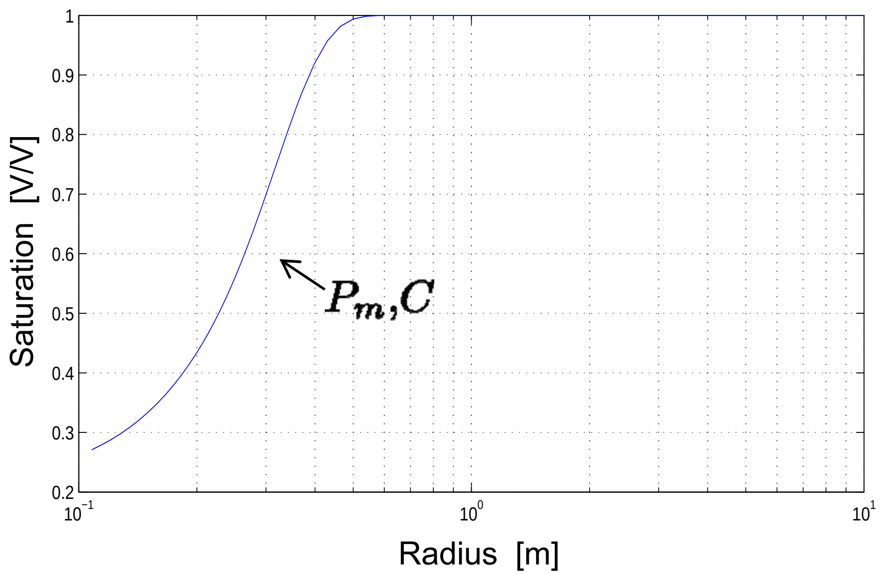


STEP 2: THE WATER SATURATION PROFILE

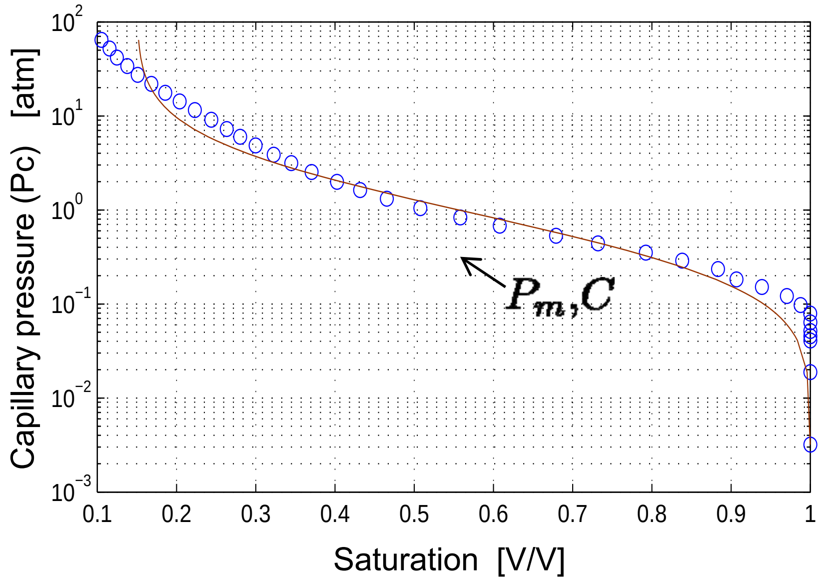
Empirical laws

- The **Kosugi** formalism is used to describe the water **saturation** from the **capillary pressure** profile :

$$S_w^*(r) = \frac{S_w(r) - S_{wirr}}{1 - S_{wirr} - S_{or}} = \frac{1}{2}\left[1 - erf\left(\frac{\ln\frac{P_c(r)}{P_m}}{\sqrt{2}\ln\sigma}\right)\right]$$



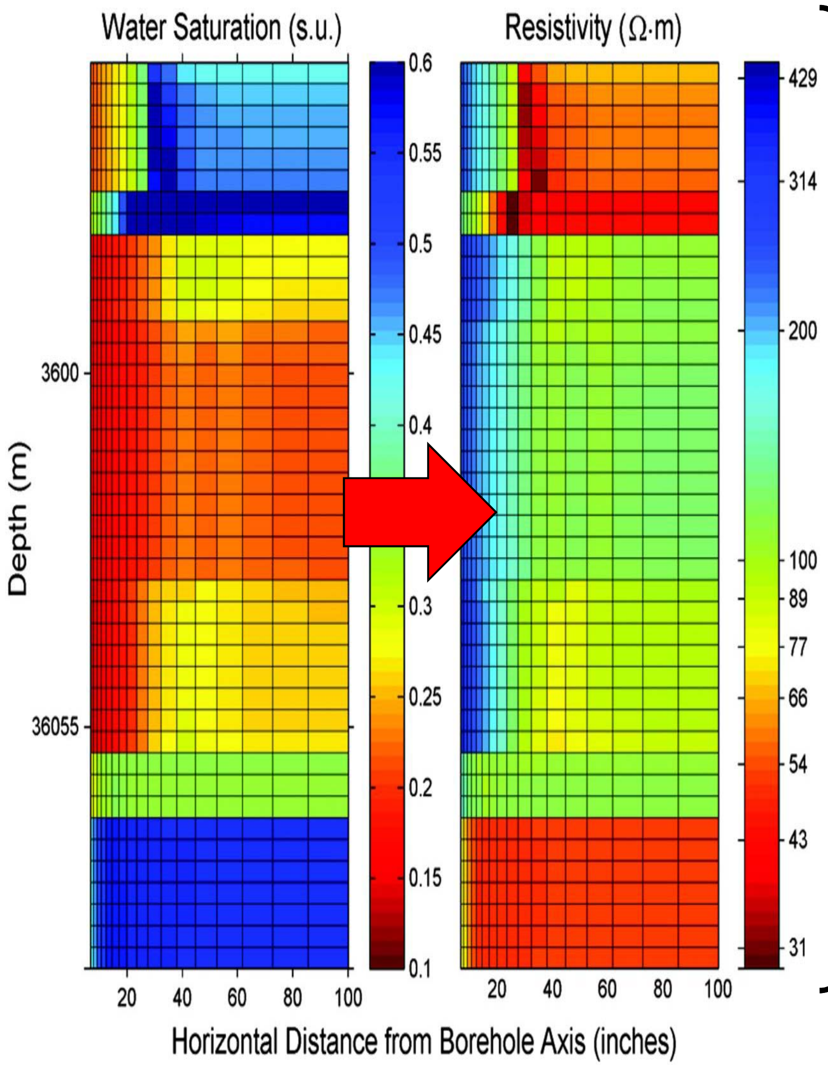
Water saturation profile



Pc-curve fitted with Kosugi formalism

STEP 3: RADIAL DISTRIBUTIONS OF LOG PROPERTIES

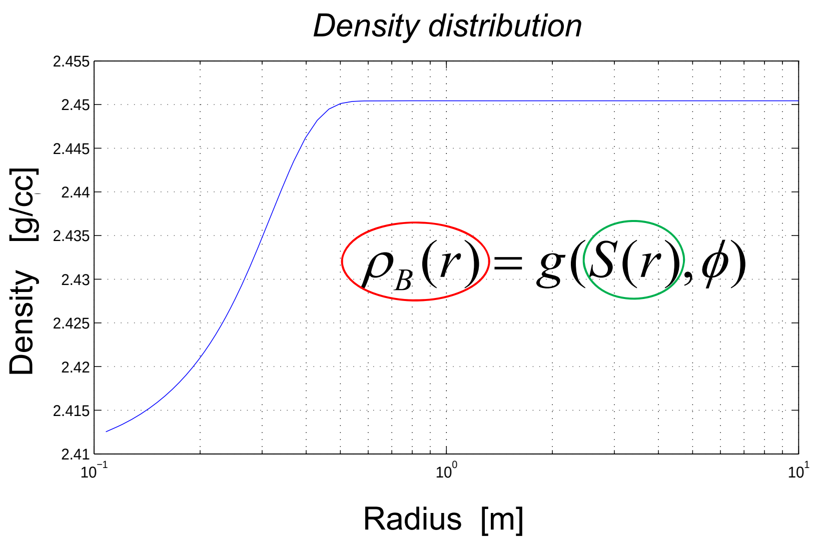
Physical laws



Empirical equations (Archie, …)

$$Rt(r) = f(S(r), \phi, Rw)$$

Linear weight balance



$$\rho_B(r) = g(S(r), \phi)$$

STEP 4: THE SIMULATION OF LOGS

Numerical models

- **Resistivity logs** simulated by solving EM equations:

$$k_h^2 = i.\omega.\mu.(\sigma_h + i.\varepsilon.\omega)$$

$$\frac{\partial^2 A_\theta}{\partial z^2} + \left[\frac{\partial}{\partial r}\left(\frac{1}{r}.\frac{\partial}{\partial r}(r.A_\theta)\right)\right] + k_h^2.A_\theta + \mu.J_S = 0$$

Electrical source term $J_s e^{-i\omega t}$
- = 0 everywhere
- Except at source

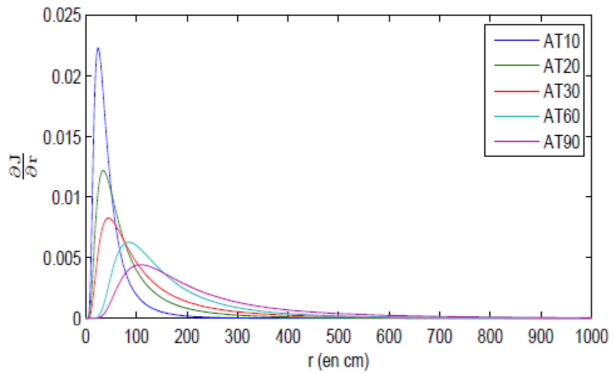
Electric potential : $A_{\vartheta,k} = |A_\vartheta| \cdot e^{i\varphi_k}$

Simulated logs: $AT = -20\log\left(\frac{|A_{\vartheta 2}|}{|A_{\vartheta 1}|}\right)$ $PS = \varphi_2 - \varphi_1$

Solved with Finite Elements and Weighted Residues Method within Dirichlet limit conditions

- **Nuclear logs** h are simulated thanks to a **convolution product** between the **tool sensitivity functions** $J(r)$ and the **physical property** distribution $X(r)$:

$$h = \int_{r_{well}}^{+\infty} \frac{\partial J}{\partial r}.X(r).dr$$



TOTAL

THE OPTIMIZATION PROBLEM

- The cost functional to minimize for **one** facies is :

$$\min_{\substack{x \\ LB \leq x \leq UB}} \|h(x) - y\|^2_{W^{-1}}$$

- For one facies with *n* frames, the **unknowns** are :
  1. Porosity, *n* unknowns
  2. Volume of clay, *n* unknowns
  3. Permeability K, n unknowns
  4. P_m , *1* unknown
  5. S_{wirr} , *1* unknown
  6. σ , *1* unknown

- The **observations** are :
  1. Resistivites, 5x*n* logs
  2. Densities, *n* logs
  3. Neutron Porosity, *n* logs

- Bound **constraints**
  - Porosity and Volume of clay between q10 and q90 of distribution provided by a stochastic soft
  - S_{wirr} between 0 and 1
  - K, P_m and σ greater than 0

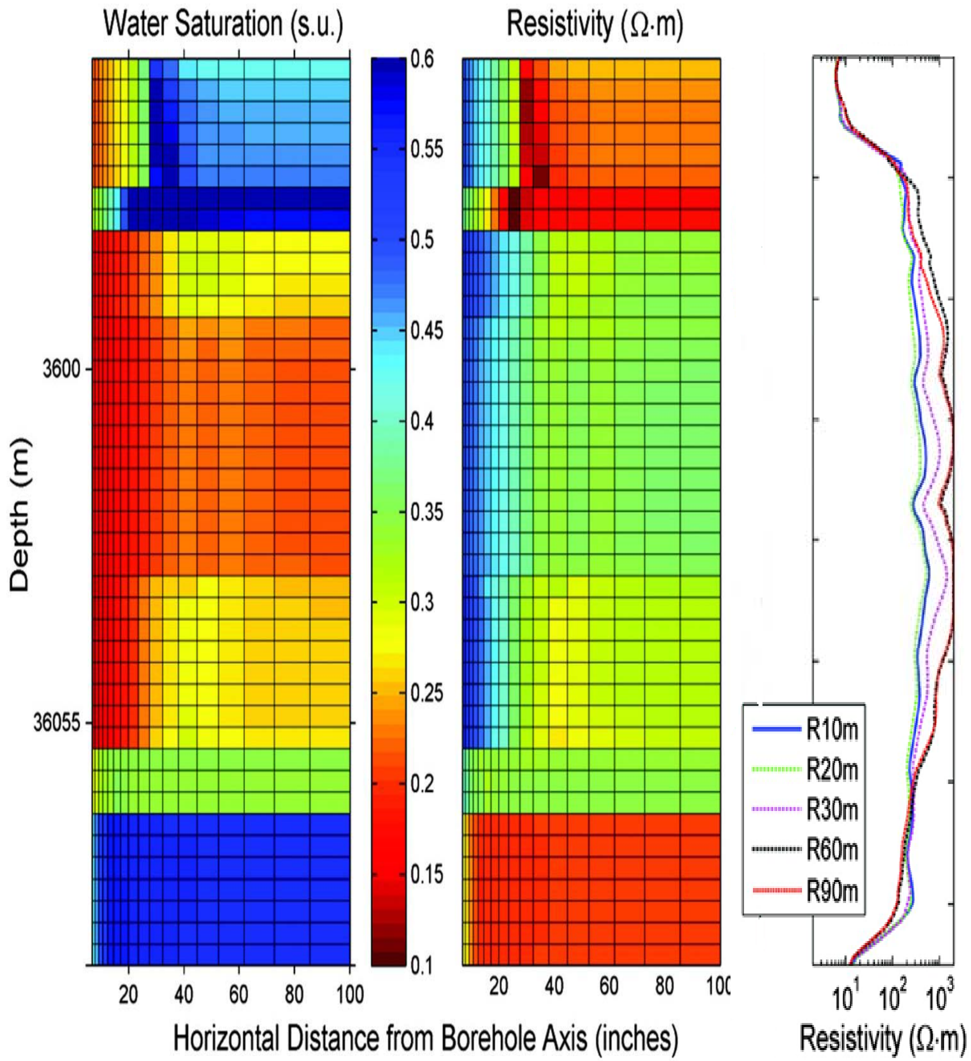
THE KEY DOMAIN FOR INTEGRATION: THE WELL BORE

- **Wellbore**: **A real in-situ injection experiment !**

⇒ **Get access to dynamics at well scale**

- **Logs** cover multiple physics, scales and in various fluid substitution proportions

Logs are the common synthetic attribute that drive the wellbore petrophysical model

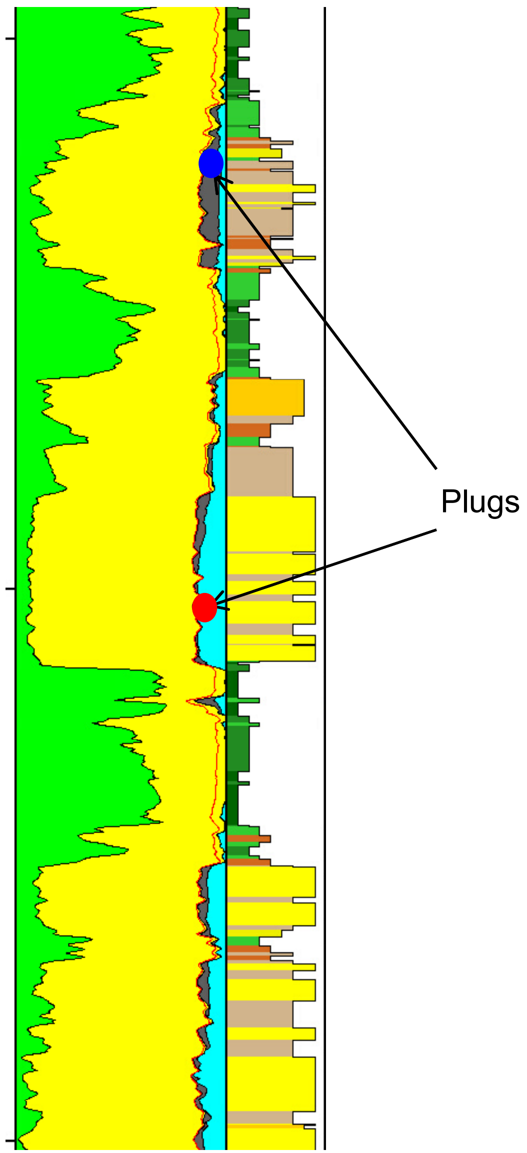


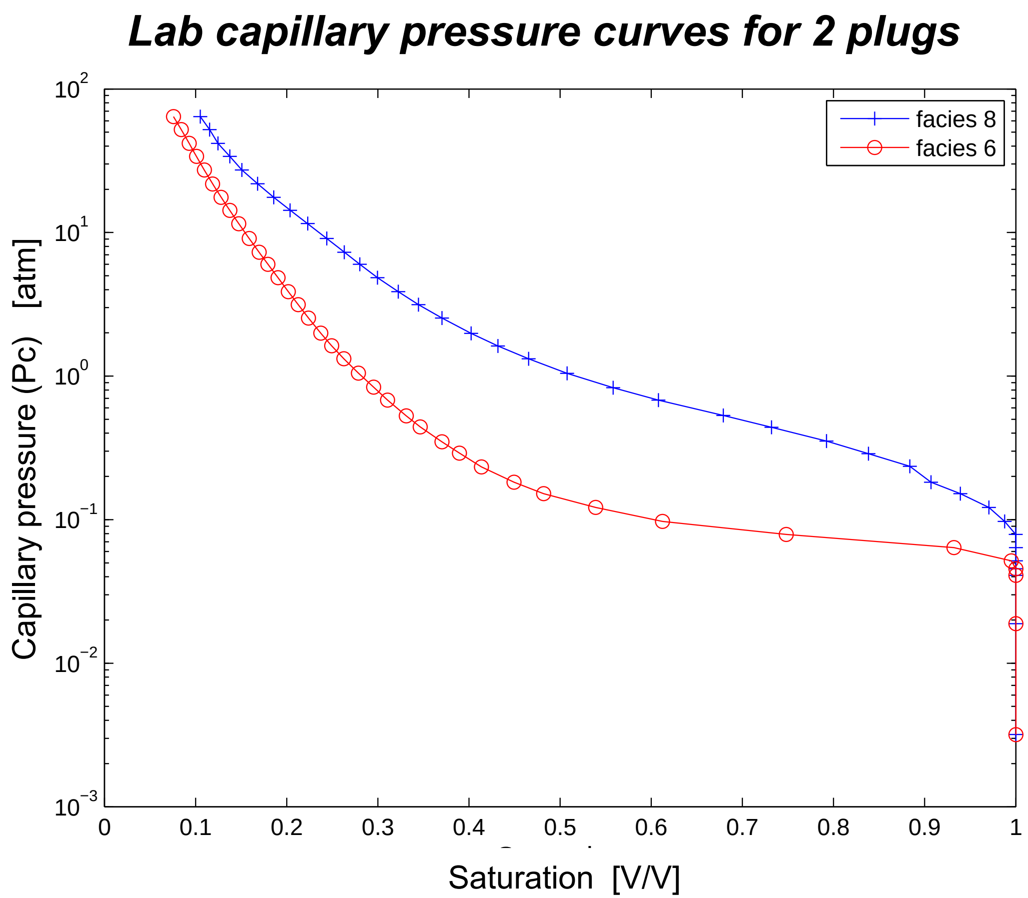
TOTAL

WELL SCALE PETROPHYSICS

PROGRESS AND FIRST RESULTS

PRESENTATION OF A WELL CASE STUDY

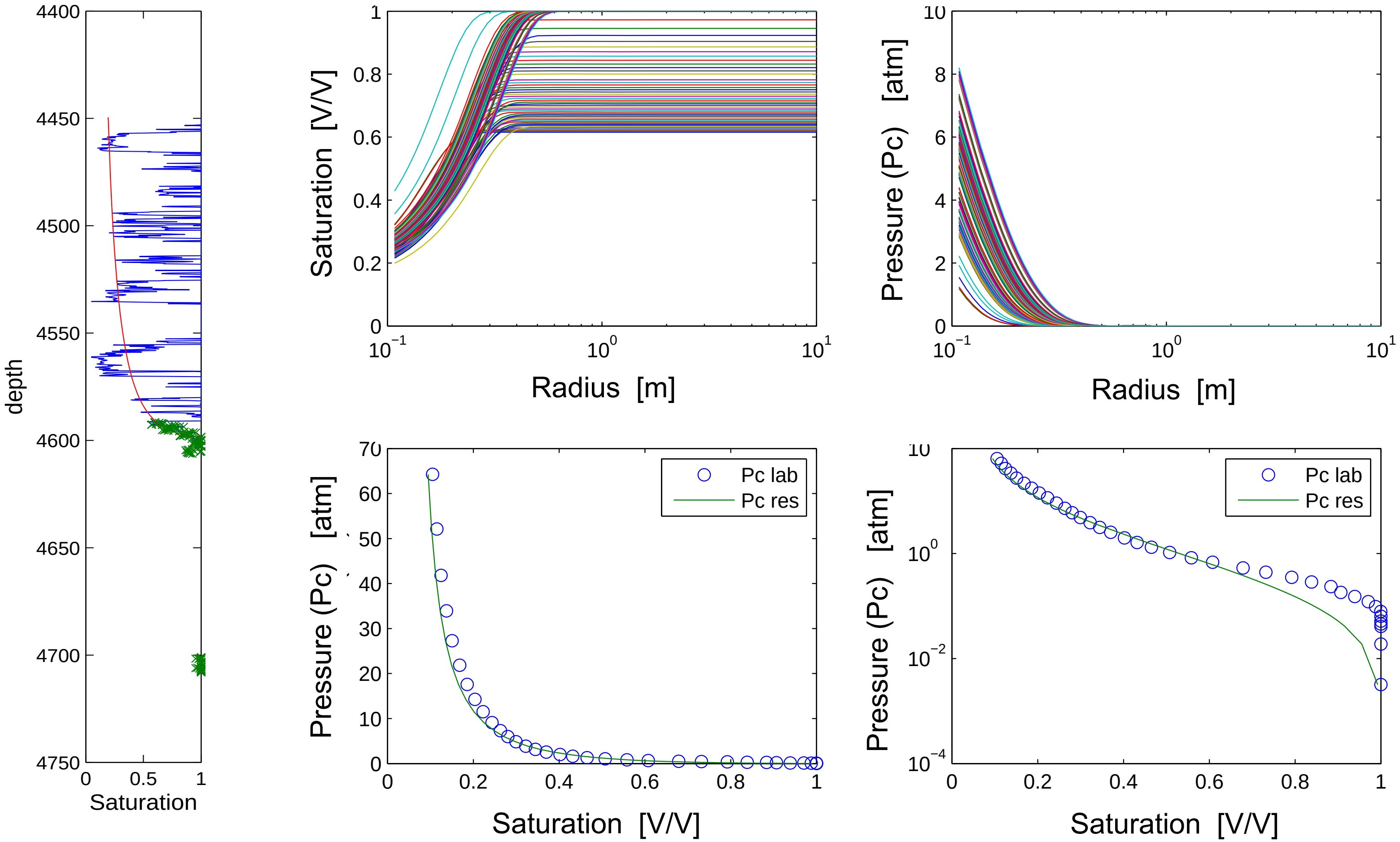




TOTAL

RESULTS FACIES 8 – CAPILLARY PRESSURE CURVE

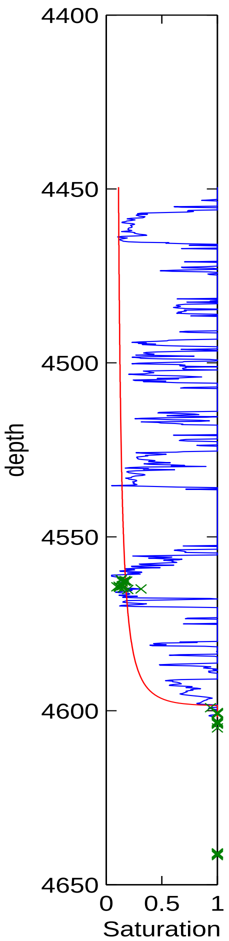
Test realized on the combination of 67 frames in the **transition zone** and 49 frames in the **water zone**.

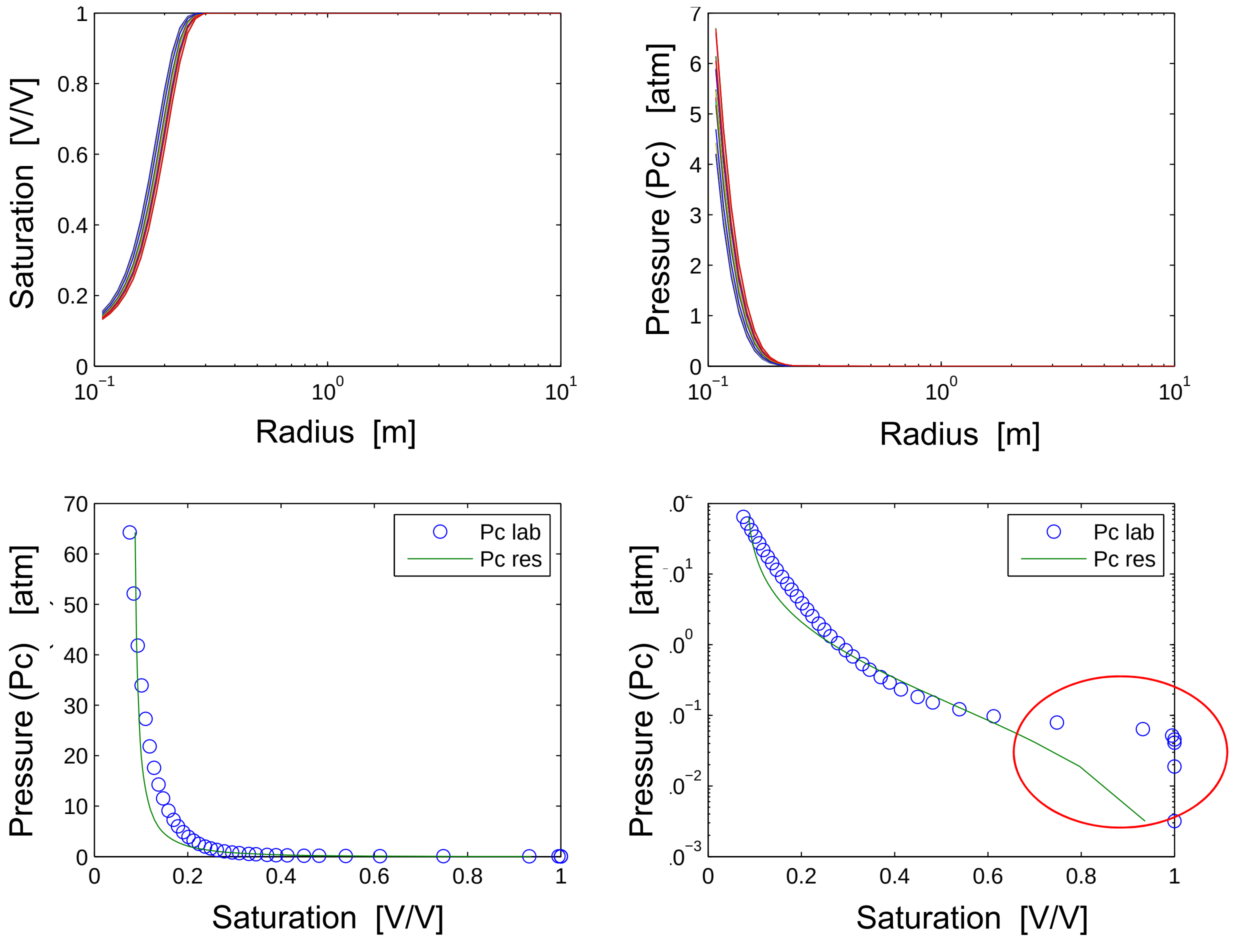


TOTAL

RESULTS FACIES 6 – CAPILLARY PRESSURE CURVE

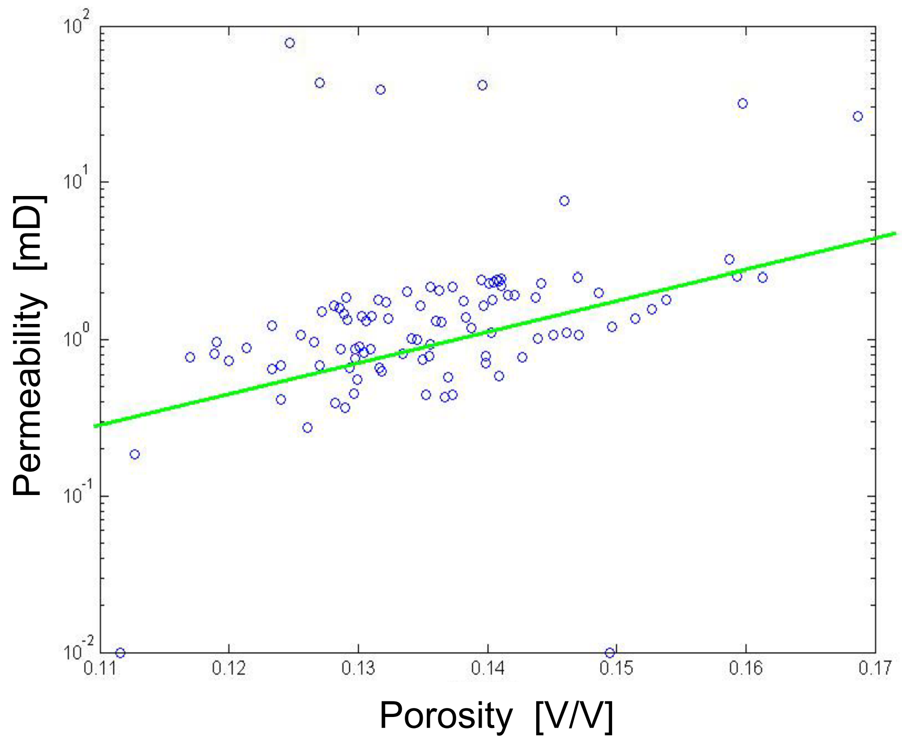
Test realized on the combination of 10 frames in the **hydrocarbon zone** and 10 frames in the **water zone**.





RESULTS VALIDITY AND MODEL ROBUSTNESS

- Lab data used as blind test:
  - Pc curves inverted succesfully for a large range of reservoir facies
  - Some independant petrophysical variables do correlate as expected



- Still some issues in poor quality facies because of weak invasion signal

- The petrophysical link between facies still under analysis

- New petrophysical contexts to be tested: drainage vs. imbibition

THE PROBLEM CHARACTERISTICS

- A data assimilation problem, with multiple **bound constraints**
- Parameters are **tightly coupled by non-linear relations** (ex. petrophysical results vs. tool sensitivity functions, local petrophysical result vs. global…)
- Input data are of **variable noise, resolution and scale** (some data are qualitative, others are quantitative)
- Need to handle pure **physical equations** (Electromagnetic wave propagation, acouctics…) with **empirical** (Archie, Kosugi) and **statistical** (facies variability) relationships
- **Multiple grids and nods**: tool simulation, wellbore modeling, facies partitioning

EXPECTATIONS AND REQUIREMENTS

- Synthetic model => should be able to integrate **all** the available data
  - Multi-physics
  - Multi-data
  - Multi-well

- The system should be agile enough to integrate **variable datasets** – easily switch from under- to over-constrained problem

- In many situations: ill-posed problem with **multiple solutions**
  - ⇒To be identified beforehand
  - ⇒Any pre-conditionning necessary ?

- Large amount of data + iterations => **computationnal performances** could be a bottleneck

CONCLUSION

CONCLUSION & WAYFORWARD

- A new domain of petrophysics is emerging, based on **numerical simulations** (physics, tools, petrophysics) and **model inversion**

- Two different choices at the moment:
  - Detailed exhaustive physics in a pure forward modeling
  - A simplified inverse approach solving one dominant problem at a time

- Remaining questions
  - Optimization with or without gradients, stochastic or deterministic ?
  - In such a global optimization approach, to which level of details the models need to be ?
  - How to evaluate beforehand the dominant physical process and driving factors to invert ?
  - Solution existence and uniqueness