Lecture Presentation

PGE385(K, M)

Advanced Formation Evaluation

CAPILLARY PRESSURE

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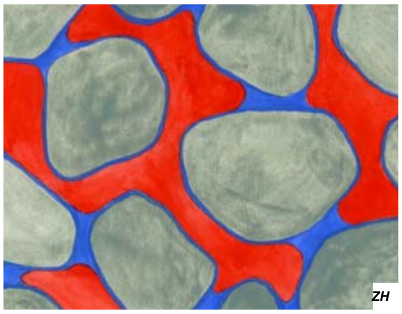
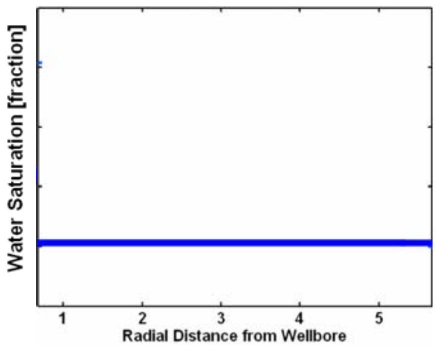
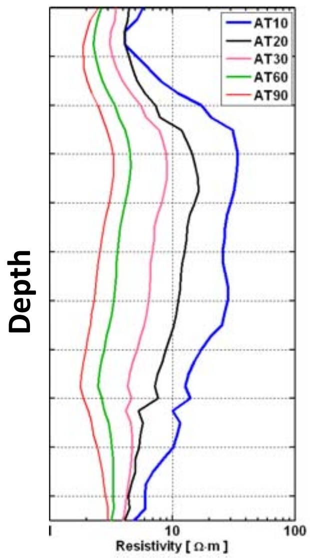
Objectives

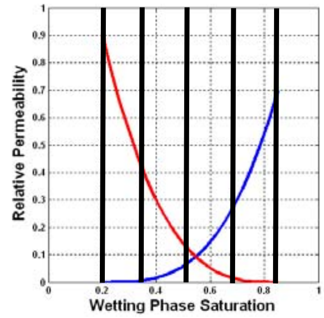
- Measure Capillary Pressure
- Convert capillary pressure to height above free-water level
- Convert height to subsurface depths where saturations are known
- Convert capillary pressure to different fluid-saturated systems
- Introduce recently-developed methods for the estimation of saturation-dependant capillary pressure

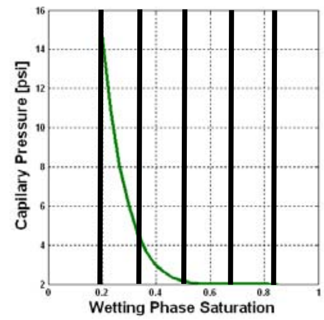
Introduction



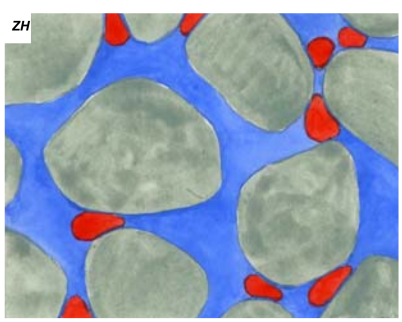


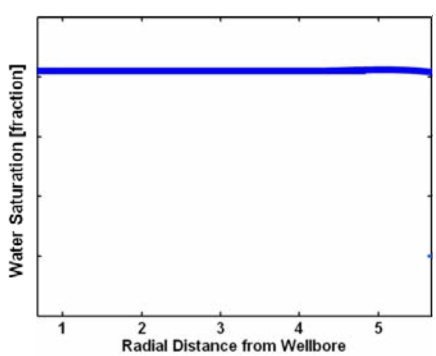


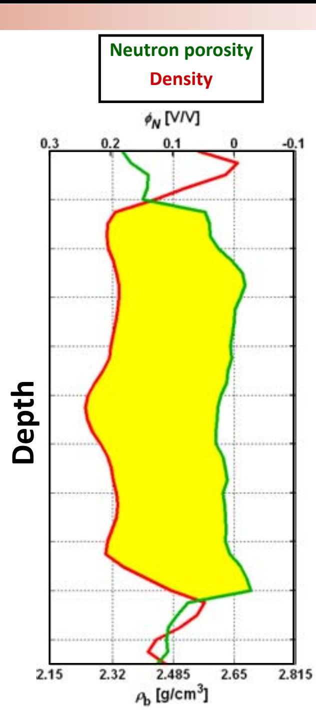


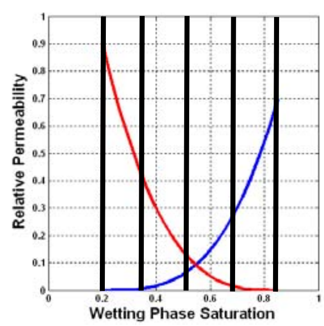


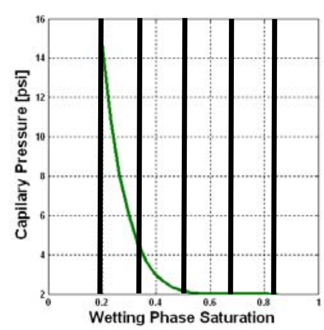
Introduction



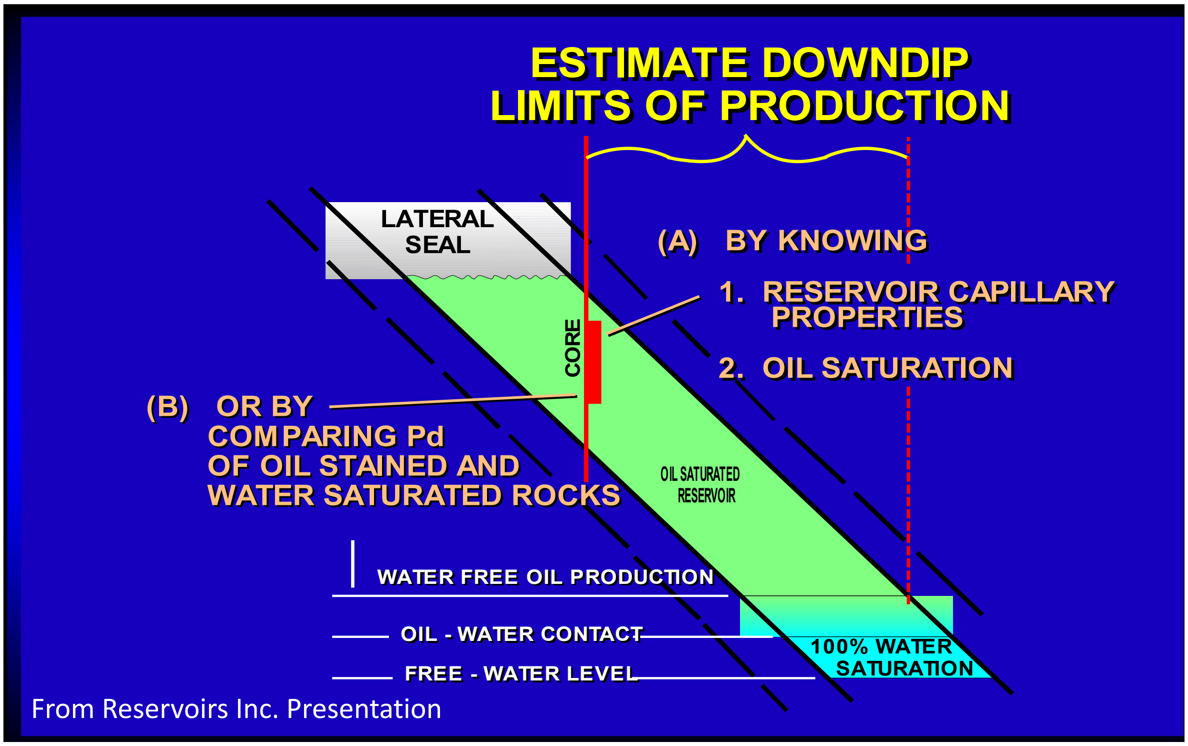








Estimating Downdip Water Contact



Conversion from Air-Brine to Hydrocarbon-Water System

$$J = P_c\, [\, k / \varphi\,]^{0.5} / (\sigma \cos \theta)$$

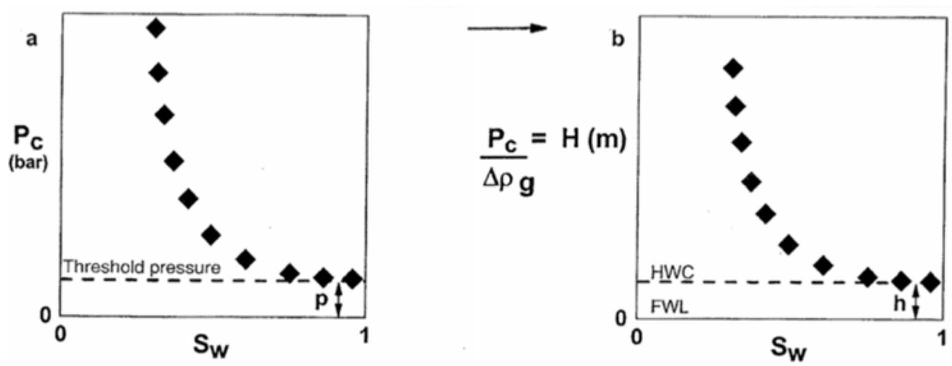
$$P_{h\text{-}w} = [(\sigma_{h\text{-}w} \cos \theta_{h\text{-}w}) / (\sigma_{ab} \cos \theta_{ab})]\, P_{ab}$$

Air-Brine :	σ_{ab} = 72 dynes/cm	$\theta_{ab} = 0^0$
Hydrocarbon-Water :	$\sigma_{h\text{-}w}$ = 18 dynes/cm	$\theta_{h\text{-}w} = 0^0$

Column Height Calculation

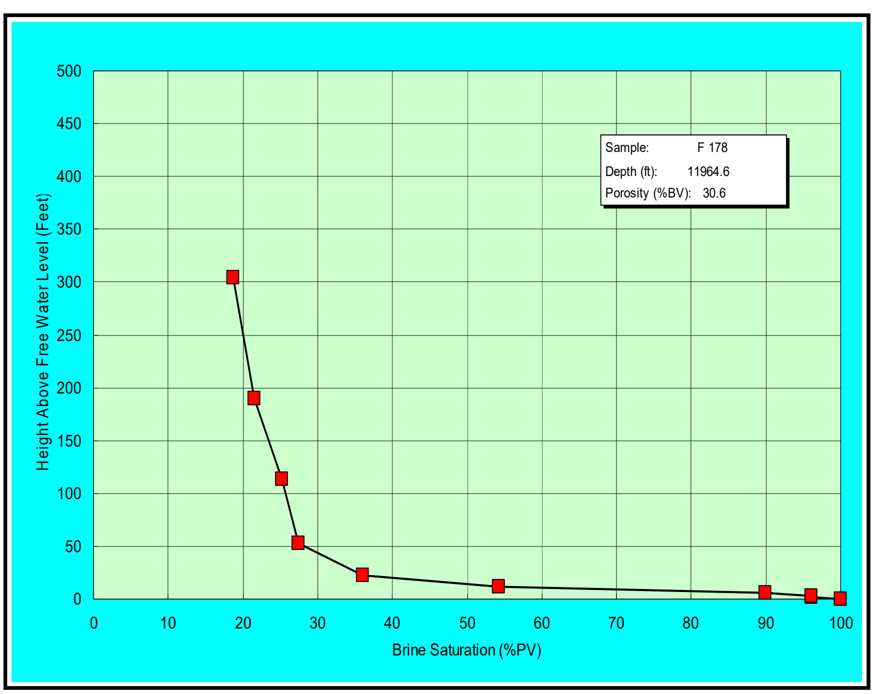
$$H = (P_c)/(\rho_w - \rho_h)$$

$$\rho_w = 1.07 \text{ g/cc} \qquad \rho_h = 0.69 \text{ g/cc}$$

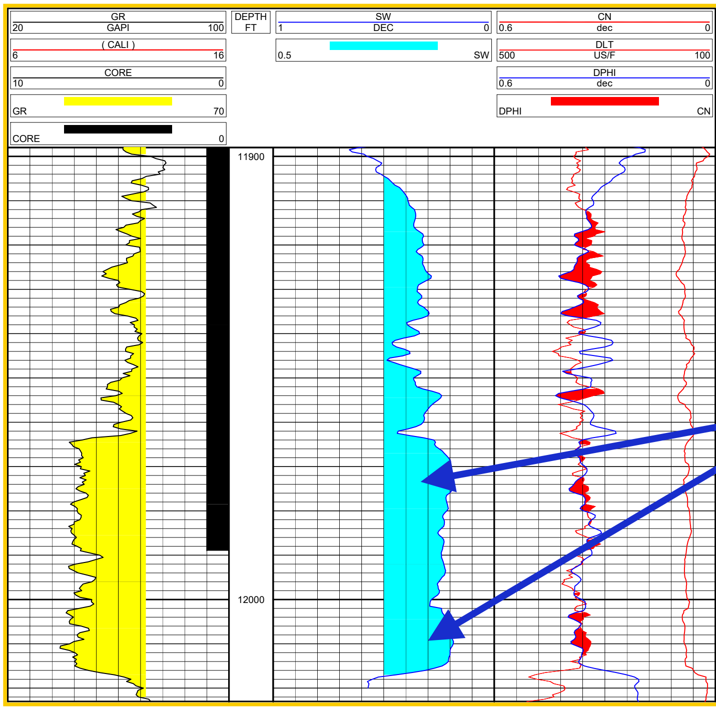


Worthington, P. F., 2002, Application of saturation-height functions in integrated reservoir description, *in* M. Lovell and N. Parkinson, eds., Geological applications of well logs: AAPG Methods in Exploration No. 13, p. 75–89.

Capillary Pressure

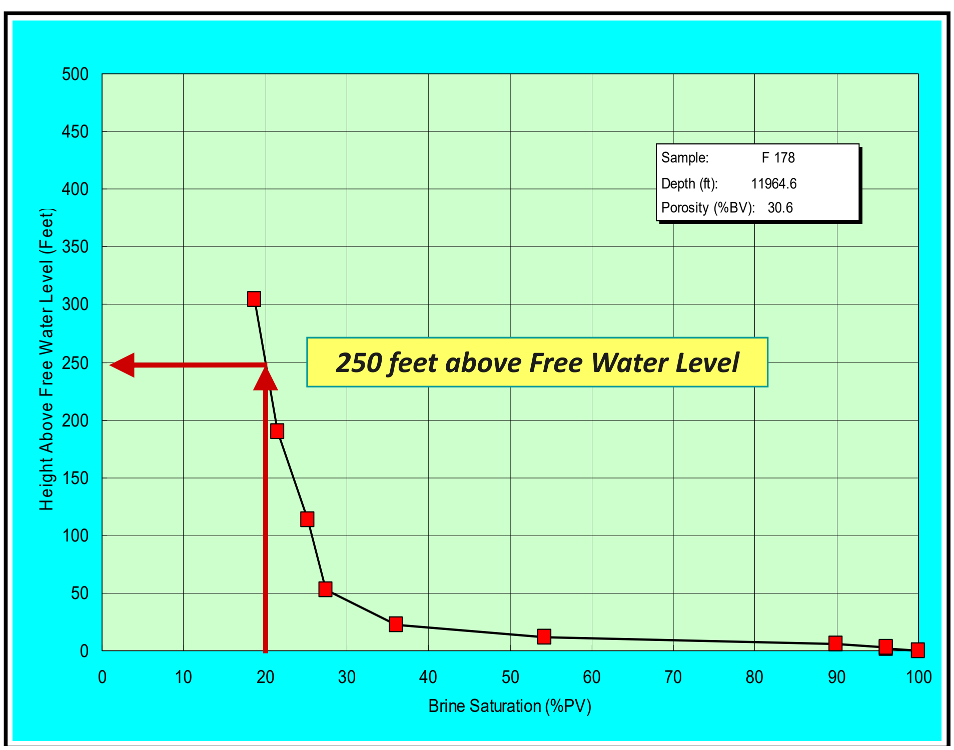


Subsurface Saturations



- **Sw = 20% in Massive Sand**

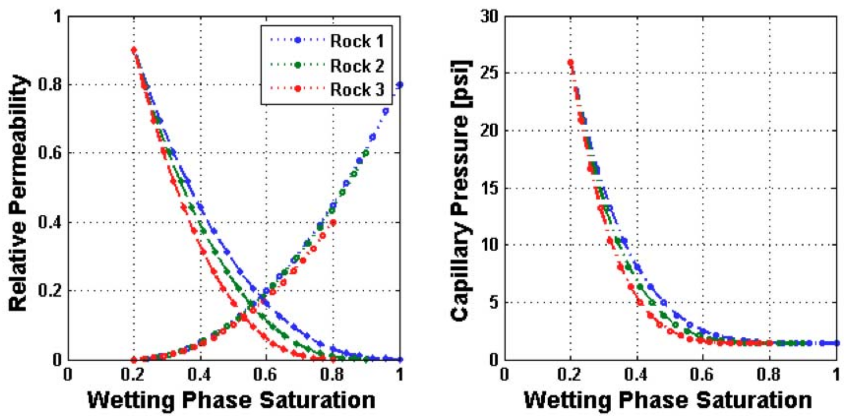
Height Above Free Water



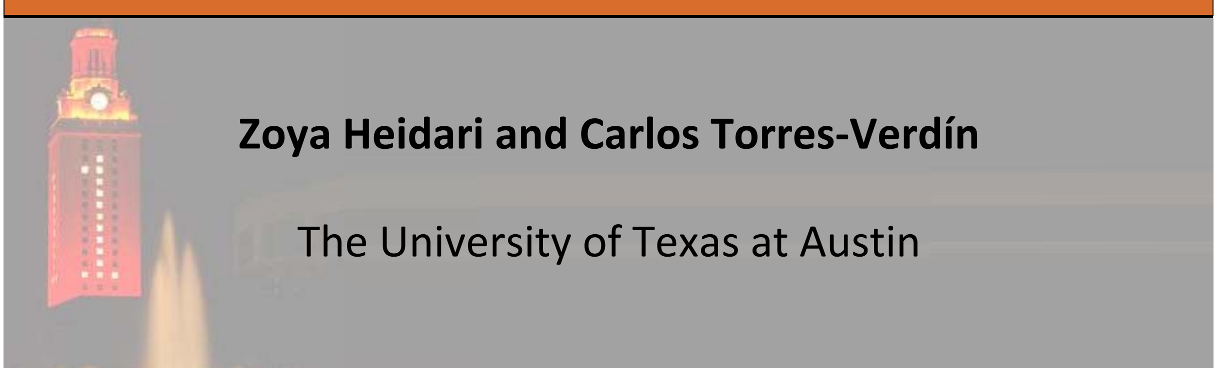
Brooks-Corey Formulation

$$P_c = P_c^0 \sqrt{\frac{\phi}{k}} \left(1 - S_N\right)^{e_p}$$

$$S_N = \frac{S_w - S_{wr}}{1 - S_{wr} - S_{nwr}}$$



ESTIMATION OF DYNAMIC PETROPHYSICAL PROPERTIES OF WATER-BEARING SANDS INVADED WITH OIL-BASE MUD FROM MULTI-PHYSICS BOREHOLE GEOPHYSICAL MEASUREMENTS



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Motivation

- Why water-saturated zones?
  - Low resistivity
  - Max sensitivity of array-induction resistivity measurements
- Why oil-base mud filtrate?
  - Immiscibility of mud-filtrate and in-situ fluid
  - Negligible effect of salinity
  - Larger separation among array-induction resistivity measurements

Outline

- Objectives
- Introduction
- Method
- Field applications
- Sensitivity analysis
- Conclusions

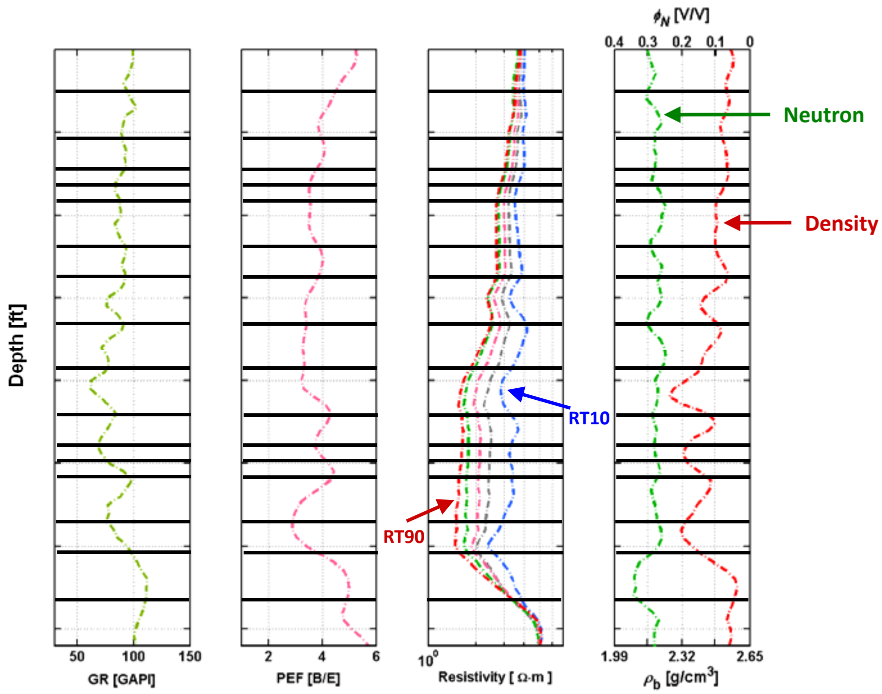
Objectives

- Obtain reliable estimates of dynamic petrophysical properties using:
  - Water-saturated and shale zones
  - Well-log numerical simulation
  - Simulation of oil-base mud-filtrate invasion
- Combined inversion:
  - Gamma-ray, PEF, sonic, array-induction resistivity, density and neutron logs

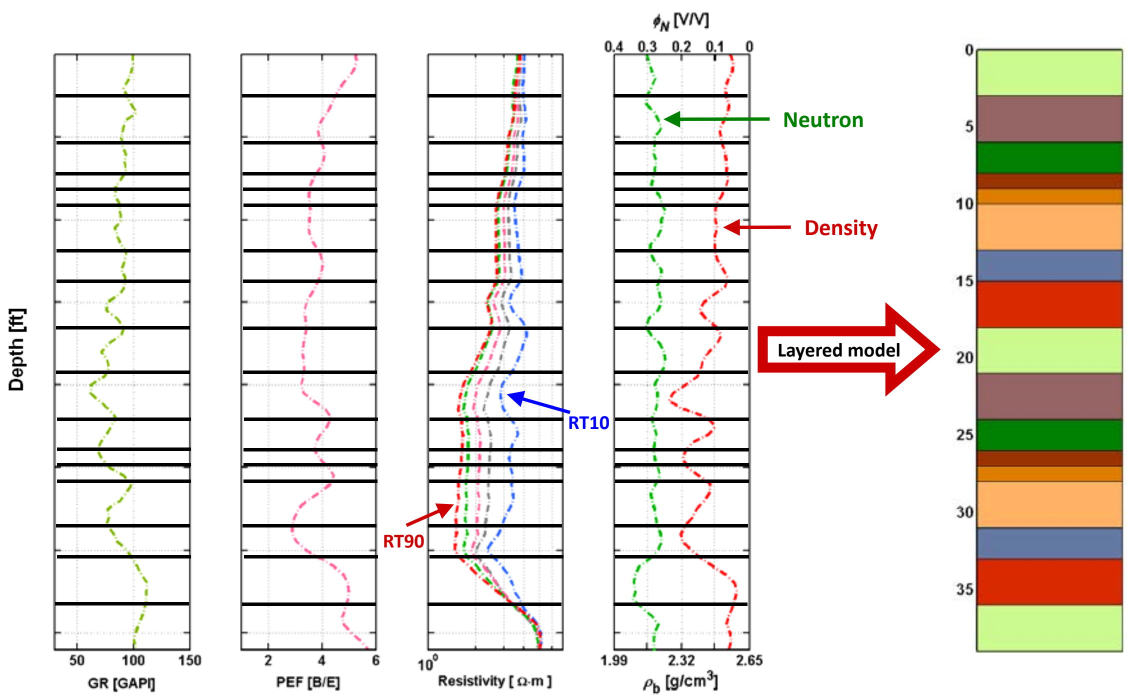
Introduction

- Conventional petrophysical interpretation:
  - Use of Archie's equation in water-saturated sands
- What is the problem?
  - Water saturation of less than 100%
    - OBM
    - Residual hydrocarbon
  - Shaly sands
  - Effect of matrix on nuclear logs

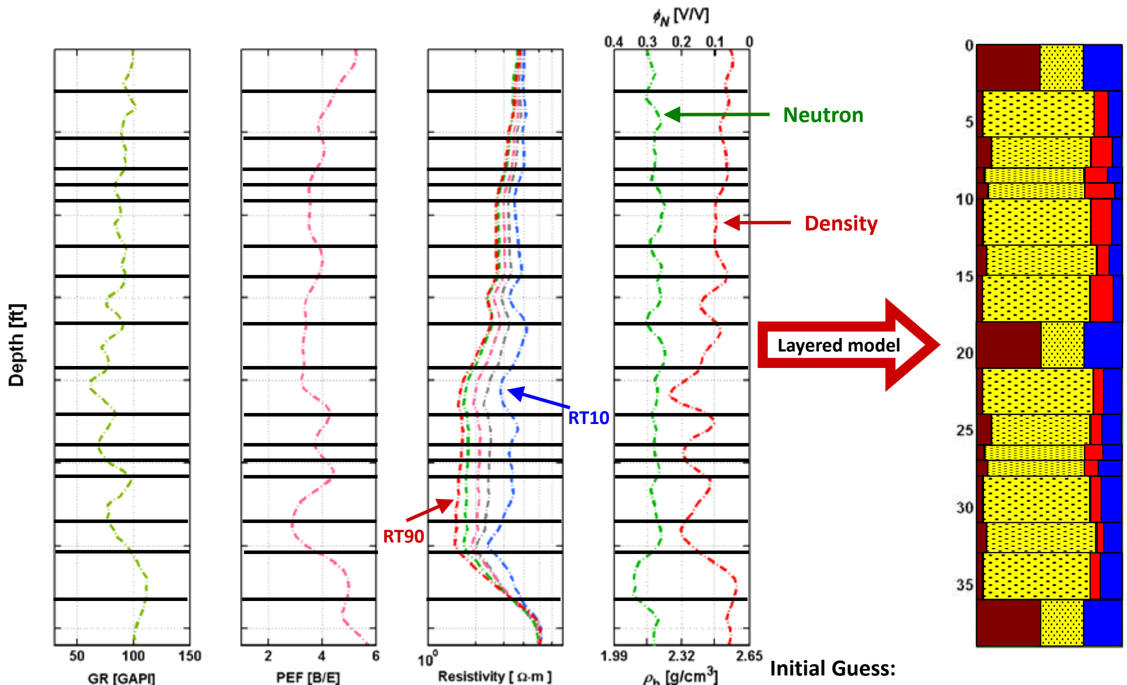
Method



Method

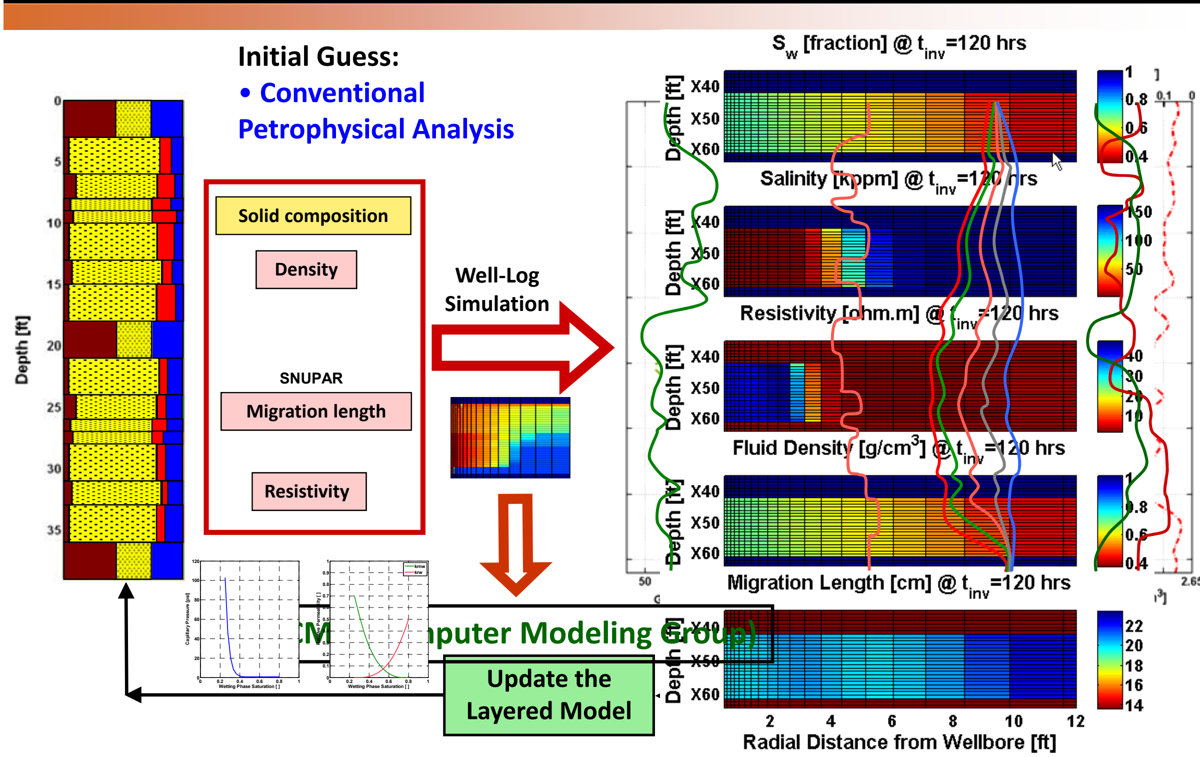


Method

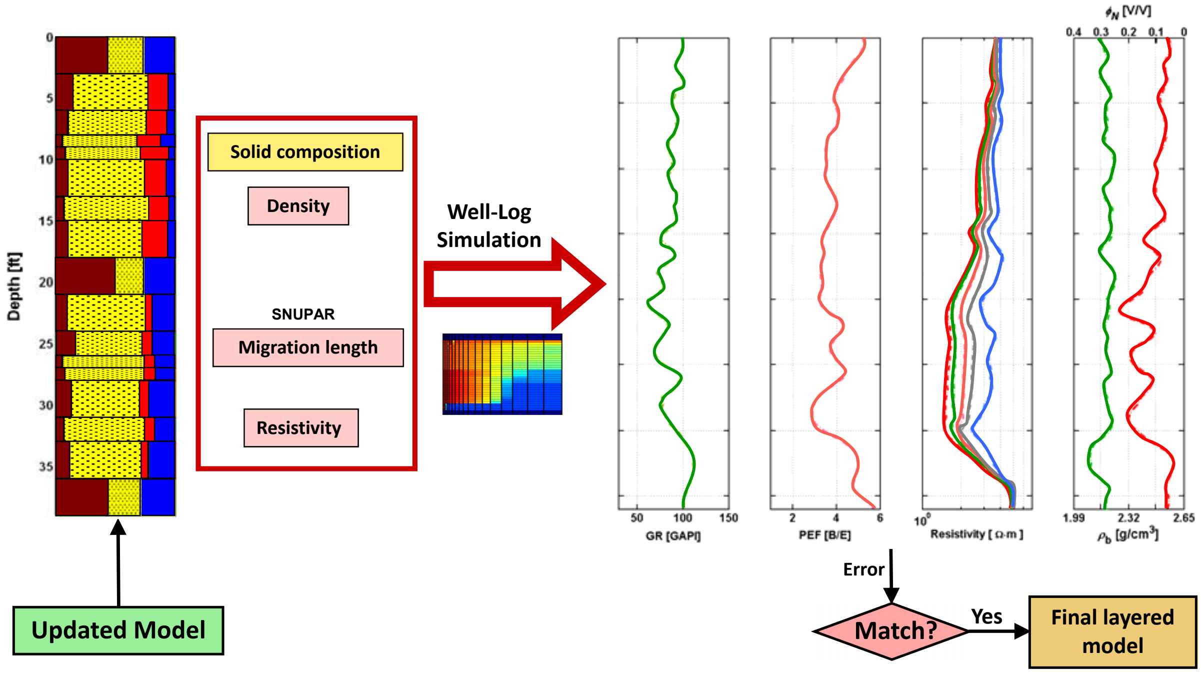


Initial Guess:
- Conventional Petrophysical Analysis

Method

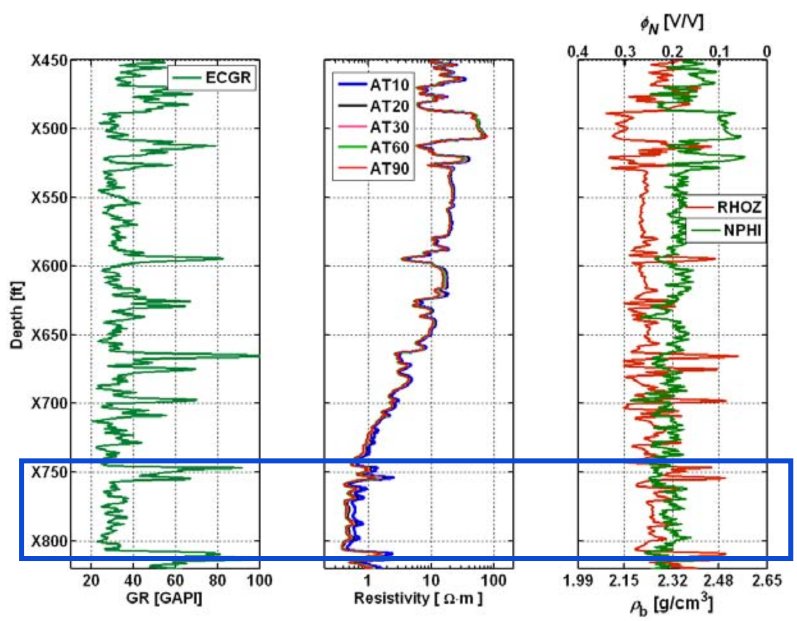


Method



Field Applications

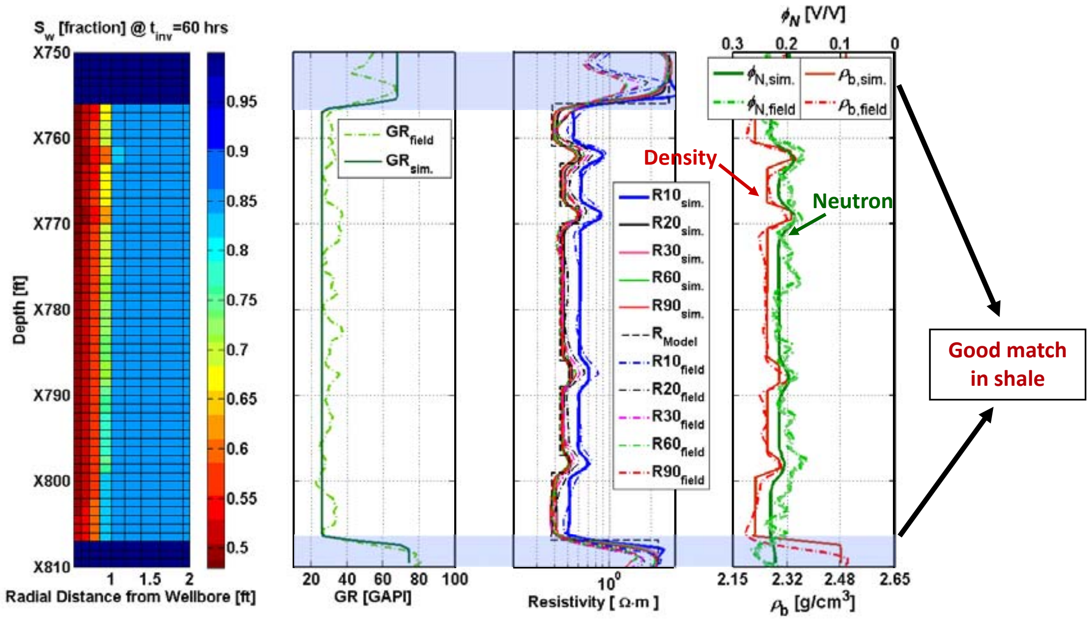
- **Field Example No. 1:** Central North Sea Sandstone (OBM)



- **Paleocene siliciclastic sequence**
- **Central North Sea**
- **Oil-Gas-Bearing Zone**
- **$k_{avg.}$ = 200 [md]**
- **$\Phi_{s,avg.}$ = 0.22**

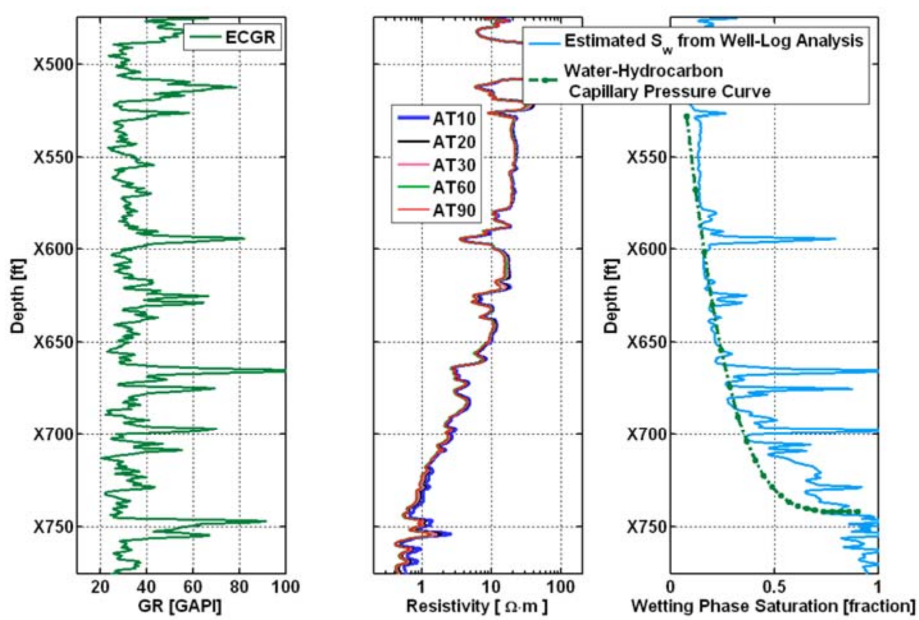
Field Applications

- **Field Example No. 1:** Central North Sea Sandstone (OBM)



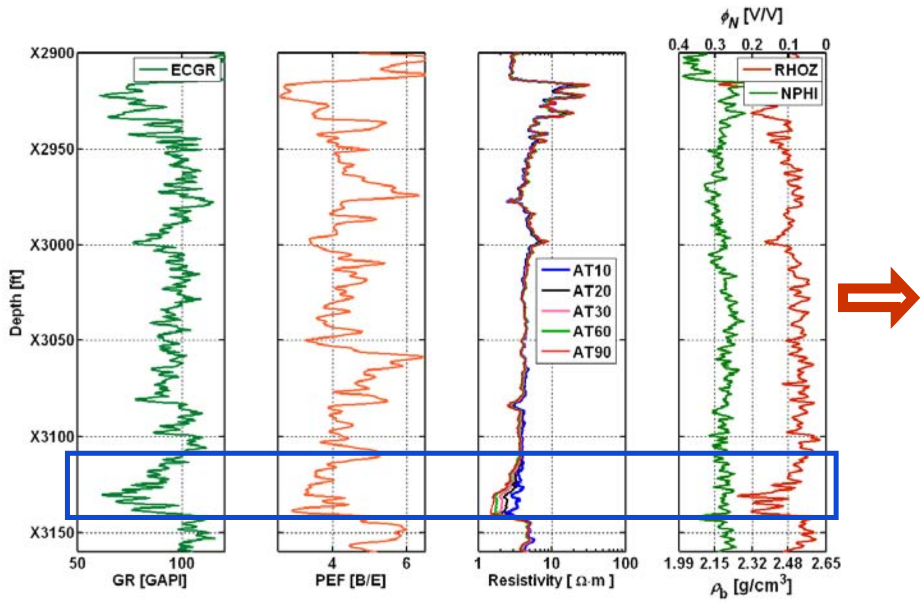
Field Applications

- **Field Example No. 1:** Cross-Validation



Field Applications

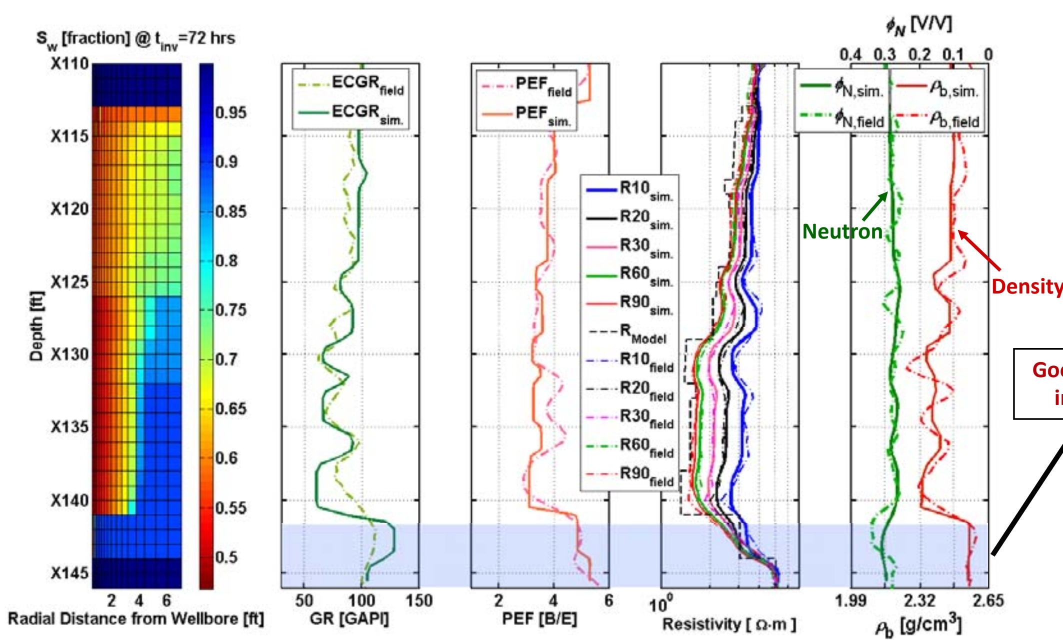
- **Field Example No. 2:** Trinidad Shaly Sand (OBM)



- **Shaly-sand sequence**
- **Delta sedimentary system**
- **Gas-Bearing Zone**
- $k_{avg.}$ **= 500 [md]**
- $\Phi_{s,avg.}$ **= 0.14**

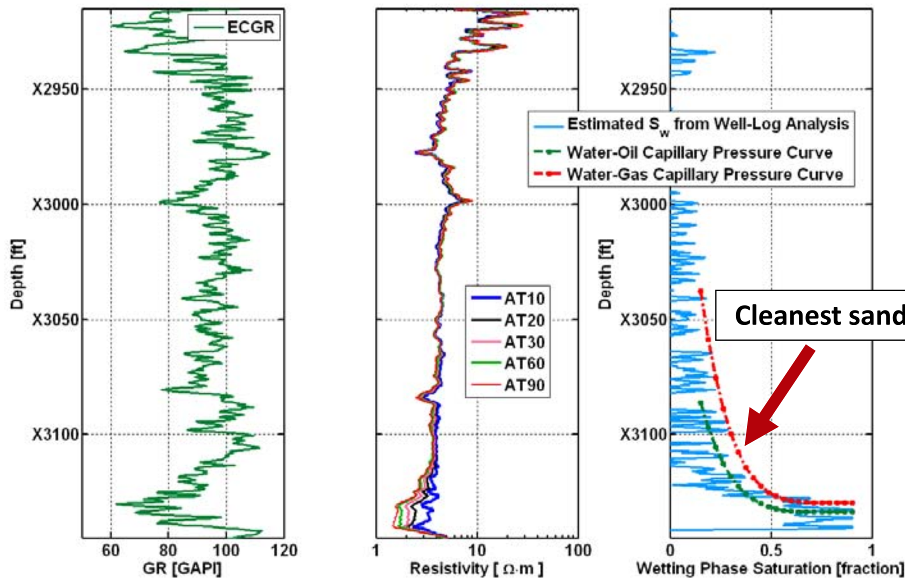
Field Applications

- **Field Example No. 2:** Trinidad Shaly Sand (OBM)



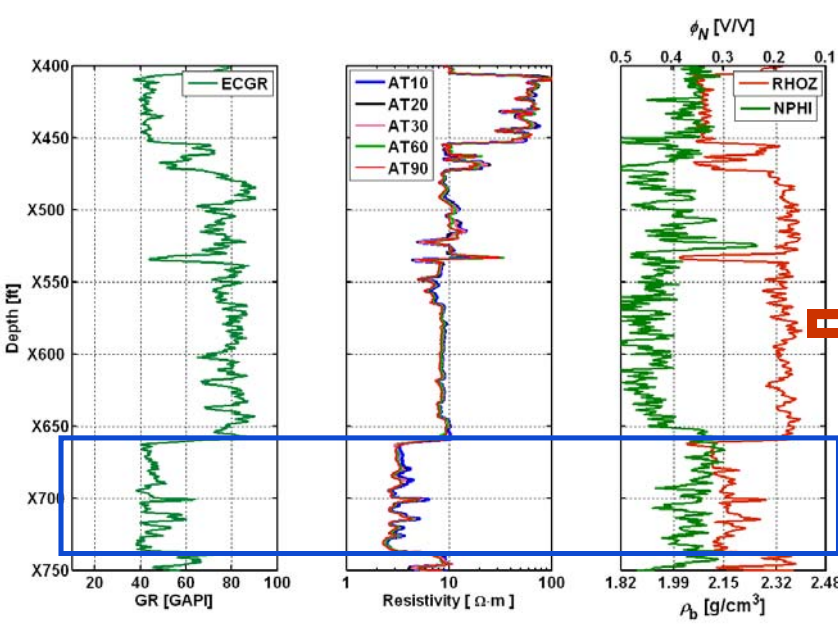
Field Applications

- **Field Example No. 2:** Cross-Validation



Field Applications

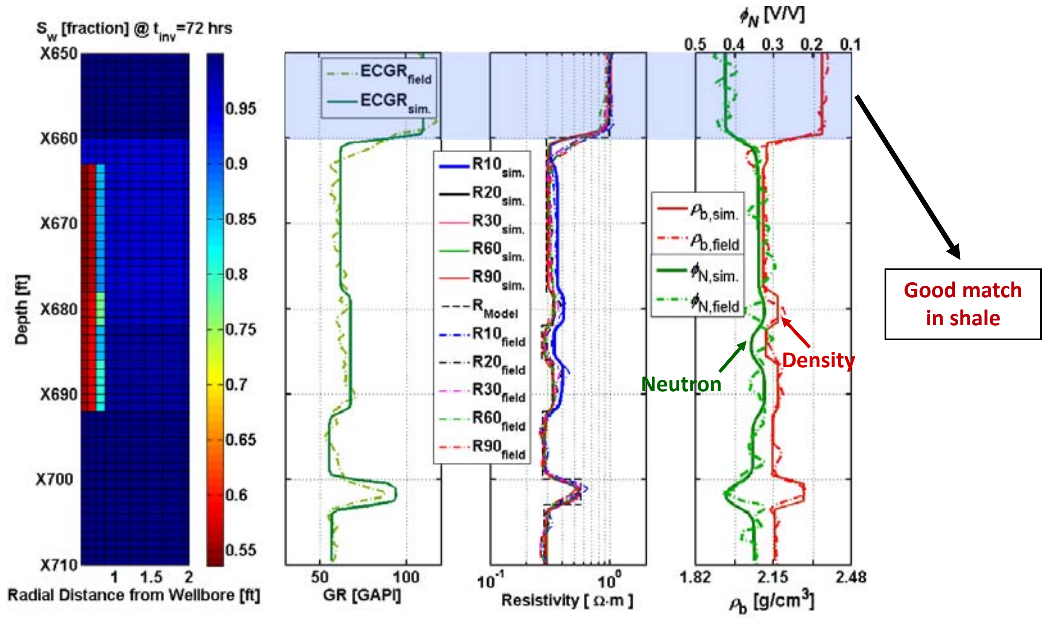
- **Field Example No. 3:** Deep-Water Gulf of Mexico (OBM)



- **Deepwater Gulf-of-Mexico**
- **Unconsolidated shaly-sand sequence**
- **Turbidite depositional system**
- **Oil-Gas-Bearing Zone**
- ***$k_{avg.}$* = 100 [md]**
- ***$\Phi_{s,avg.}$* = 0.25**

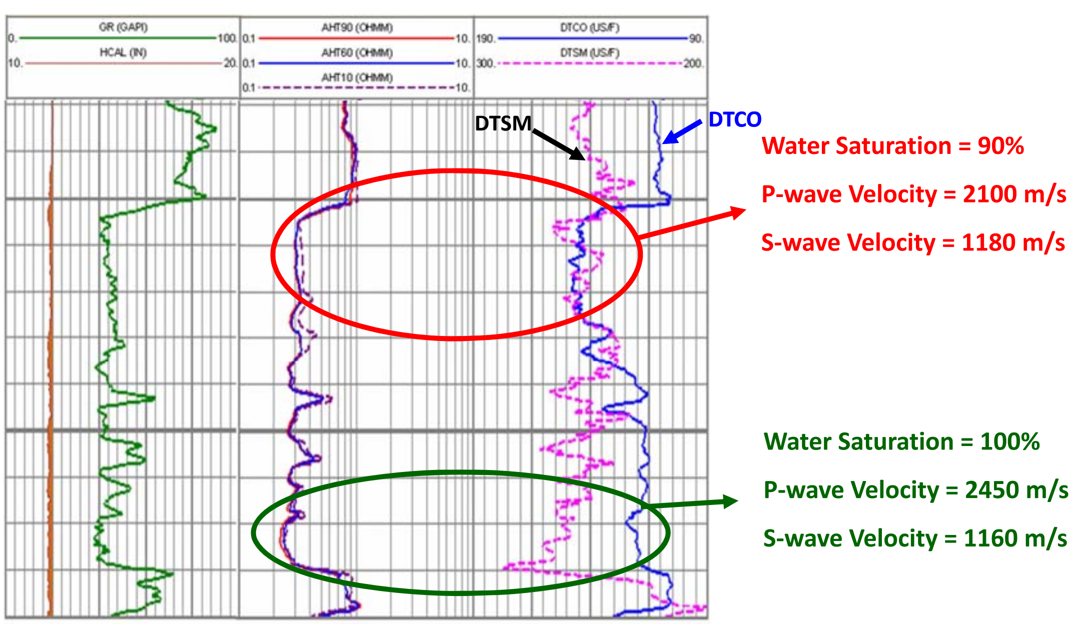
Field Applications

- **Field Example No. 3:** Deep-Water Gulf of Mexico (OBM)



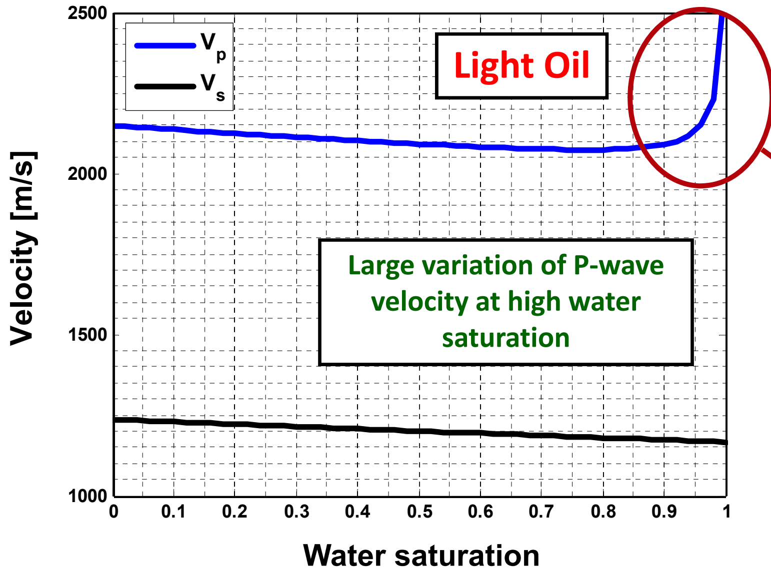
Field Applications

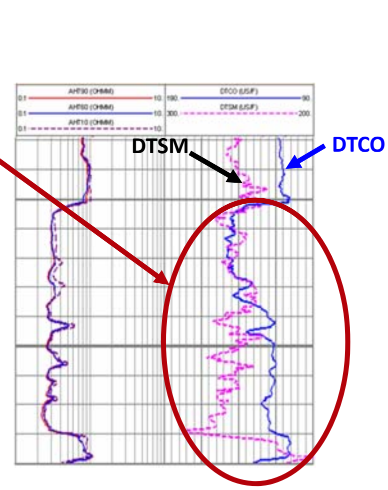
- **Field Example No. 3:** Sonic measurements



Field Applications

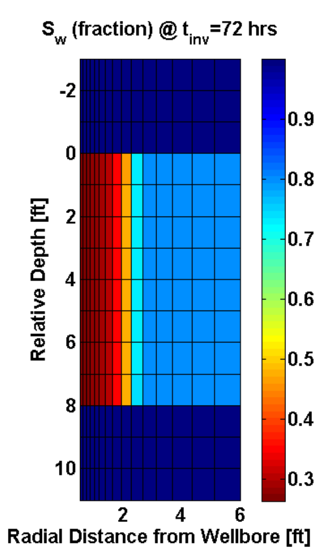
- **Field Example No. 3:** Sonic measurements





Sensitivity Analysis

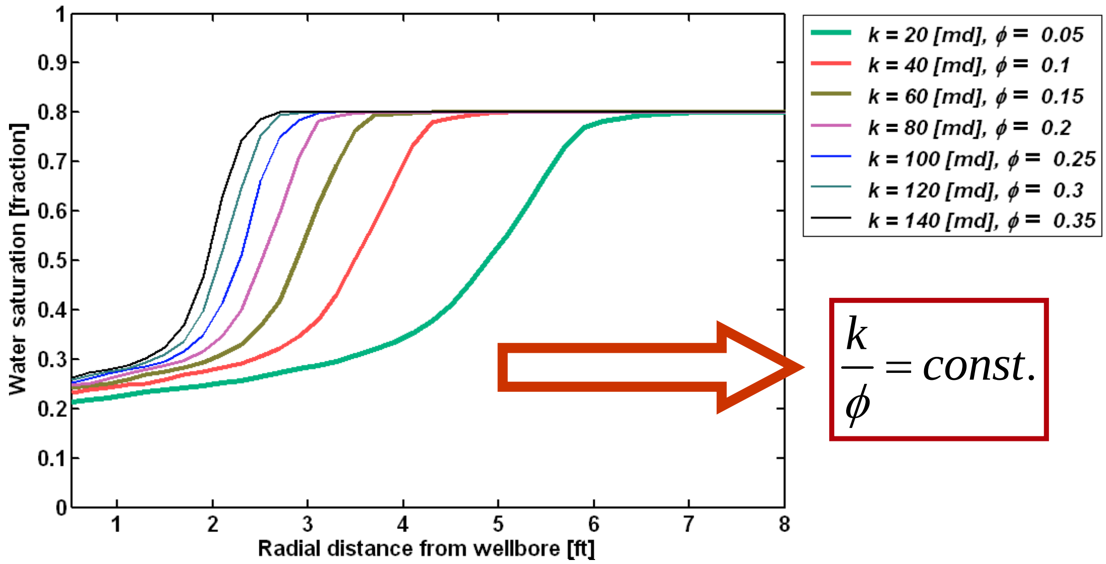
- **Assumed synthetic case for sensitivity analysis**



- **OBM**
- **Oil formation**
- **Water-saturated zone**
- **Clean sand**
- **$S_{w,initial}$ = 0.80**
- **$S_{w,irr}$ = 0.15**
- **t_{inv}= 3.0 Days**

Sensitivity Analysis

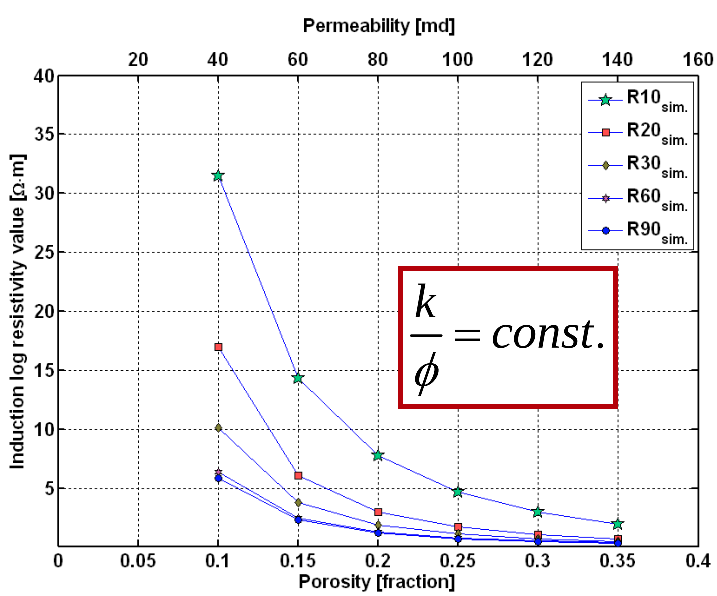
- **Sensitivity analysis on porosity and permeability**



$$\frac{k}{\phi} = const.$$

Sensitivity Analysis

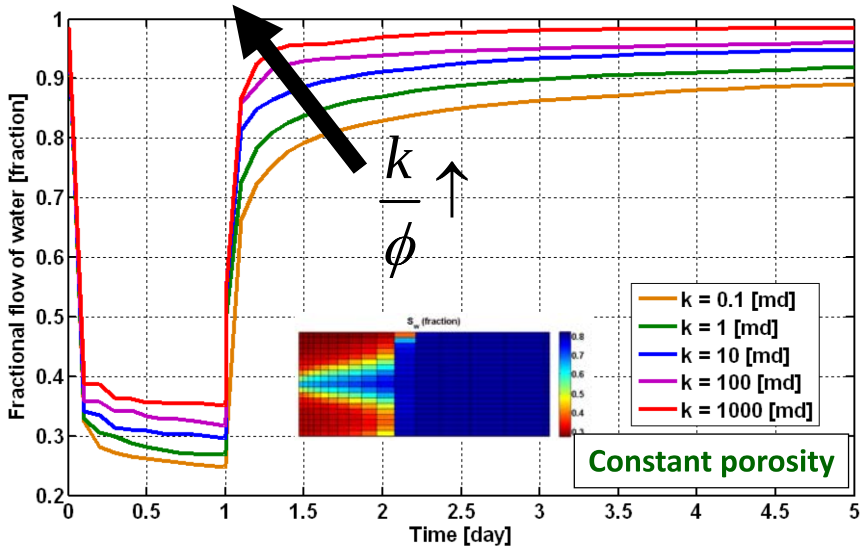
- **Sensitivity analysis on porosity and permeability**



$$\frac{k}{\phi} = const.$$

Sensitivity Analysis

- **Simulation of formation-tester measurements**



Conclusions (1)

- Use water-saturated and shale zones to estimate dynamic petrophysical properties in presence of OBM:
  - Low resistivity ➔ Max sensitivity of resistivity measurements
  - Immiscibility of mud-filtrate and in-situ fluid
  - Negligible effect of salinity
  - Higher separation in array-induction resistivity measurements
  - Reduces non-uniqueness of results

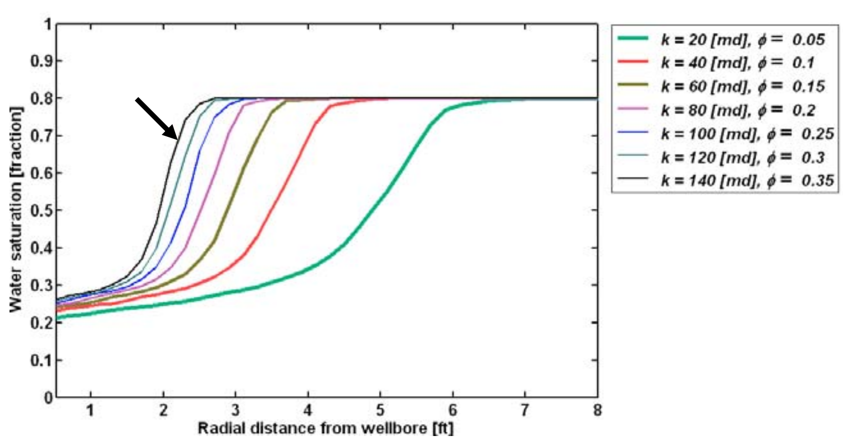
Conclusions (2)

- Use Gamma-Ray, PEF, Sonic, Resistivity and Nuclear logs:
  - Reduces non-uniqueness of results
  - Enables to estimate matrix composition as well as fluid distribution

- Three challenging field examples
  - Wide range of porosity and permeability
  - Cross-validation of estimated capillary pressure curves by comparison to water saturation profile

Conclusions (3)

- Increasing porosity and permeability decreases the efficiency of the method



Field Applications

- **Field Example No. 3:** Sonic measurements