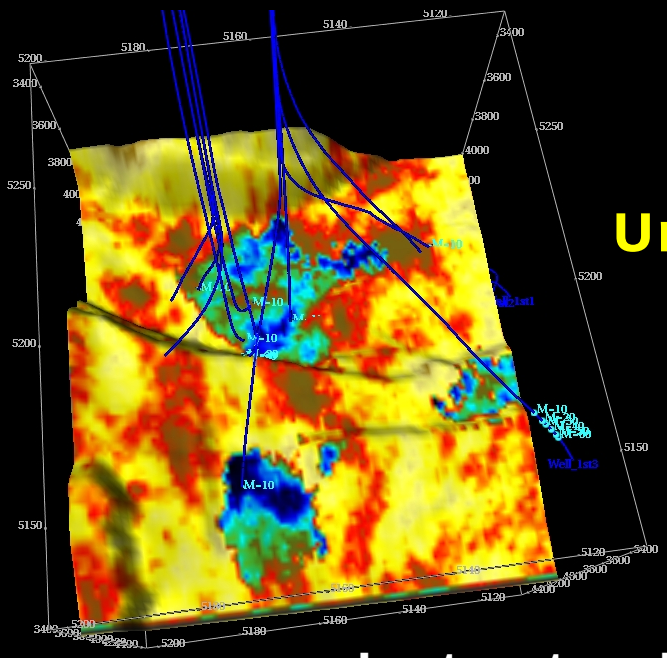
Advanced Multi-Well Formation Evaluation



PGE385K
Unique No. 20335

Fall 2021

Instructor: Dr. Carlos T. Verdín

INSTRUCTOR:

Carlos Torres-Verdín, Ph.D.

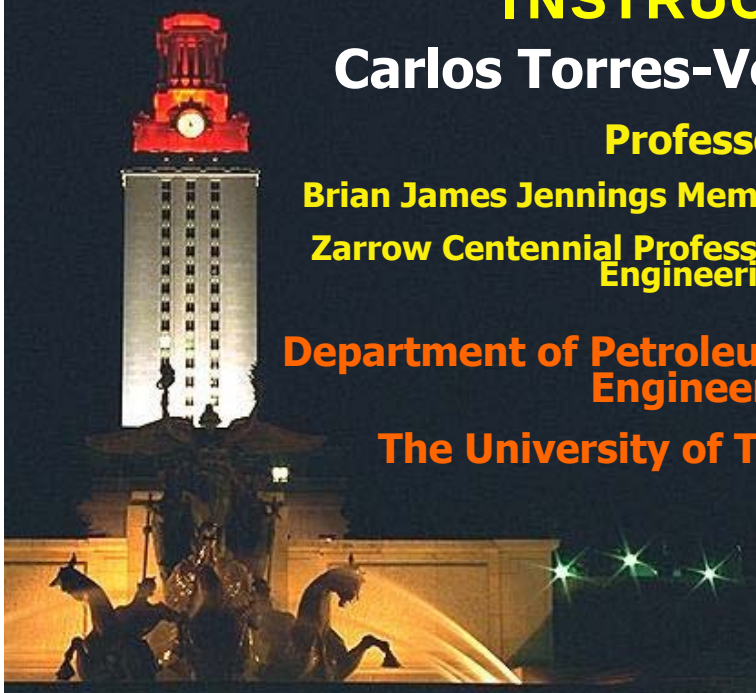
Professor

Brian James Jennings Memorial Endowed Chair

Zarrow Centennial Professorship in Petroleum Engineering

Department of Petroleum and Geosystems Engineering

The University of Texas at Austin



https://faculty.engr.utexas.edu/torresverdin/home

COURSE DESCRIPTION

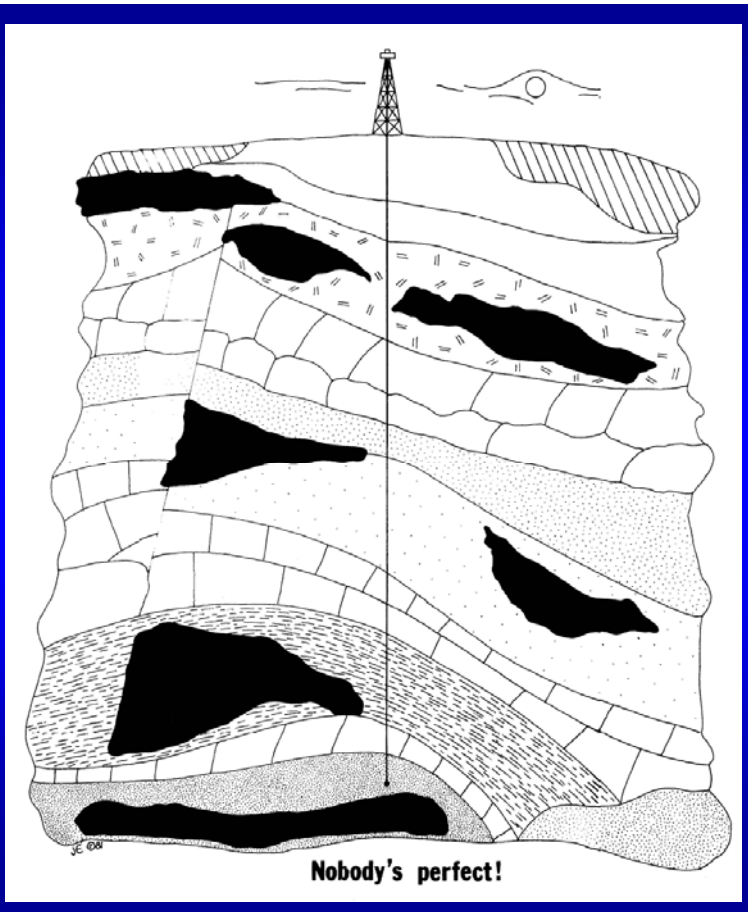
Introduction to:

(a) Advanced Borehole Logging Instruments,

(b) Modern Petrophysical Interpretation Methods of Borehole Logging Measurements,

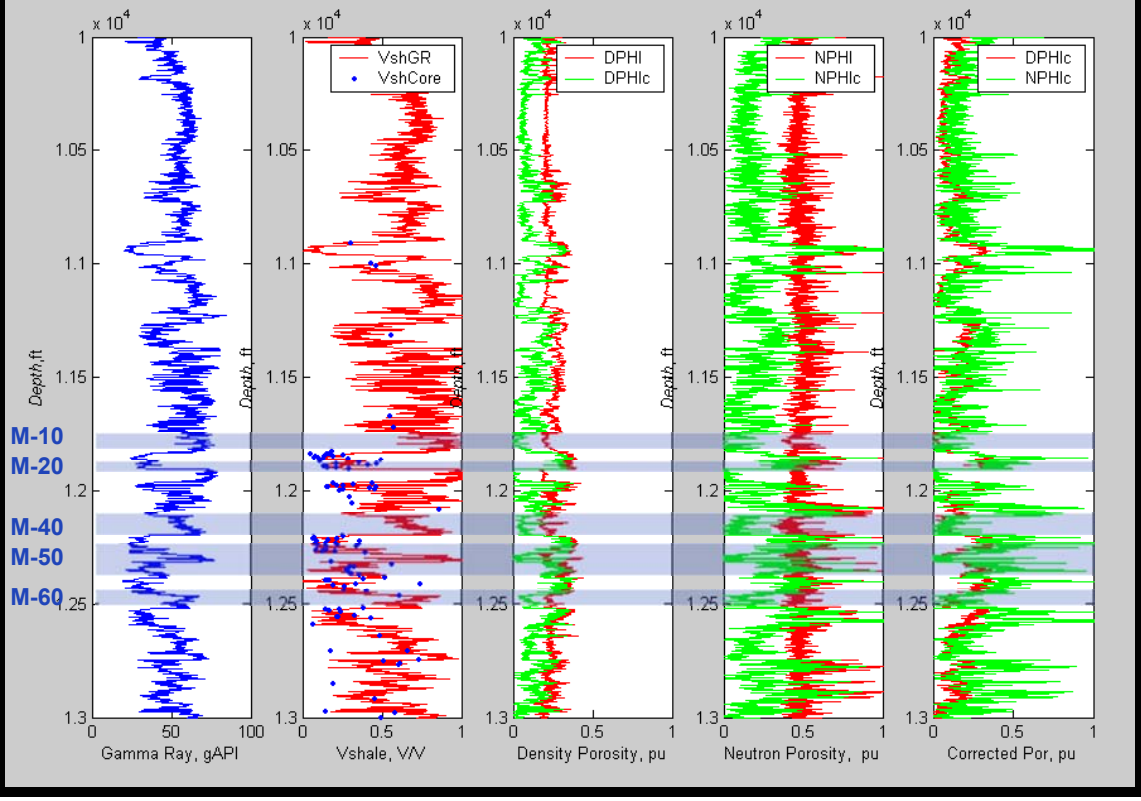
(c) Multi-Well Geological and Petrophysical Evaluation of Borehole Logging Measurements and Rock-Core Data,

(d) INTEGRATION of Well Logs, Core Data, Geological Information, Seismic Measurements, and Fluid Production Data in the Construction of Hydrocarbon Reservoir Models Amenable to Simulation of Production.

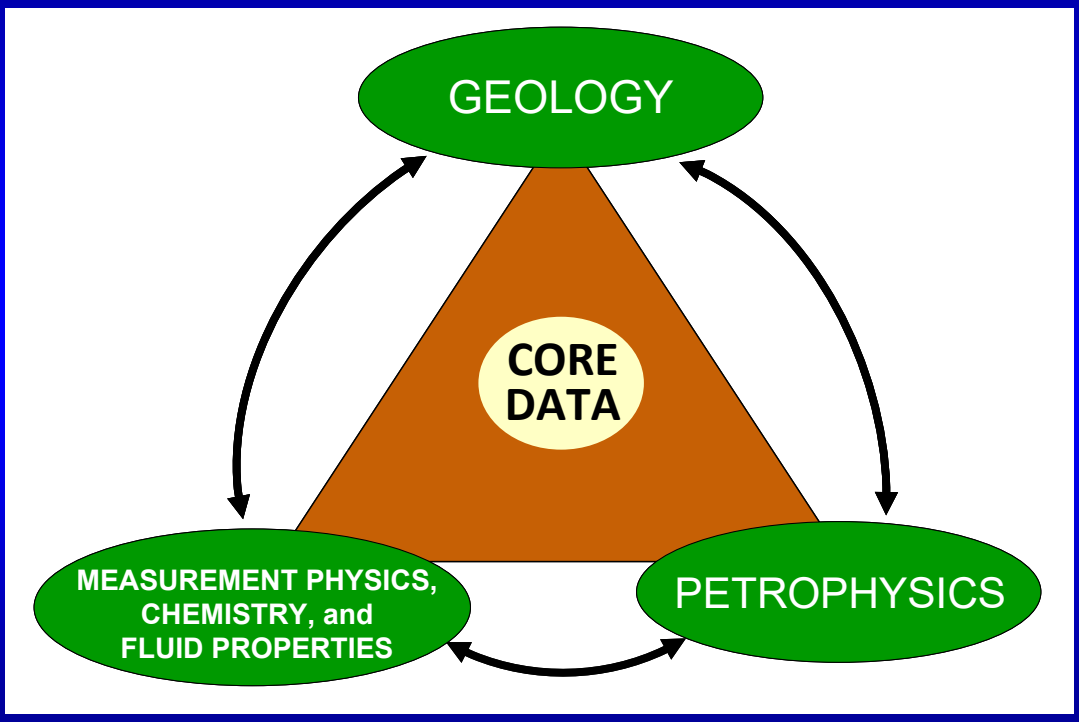


What went wrong?

What is a well log?



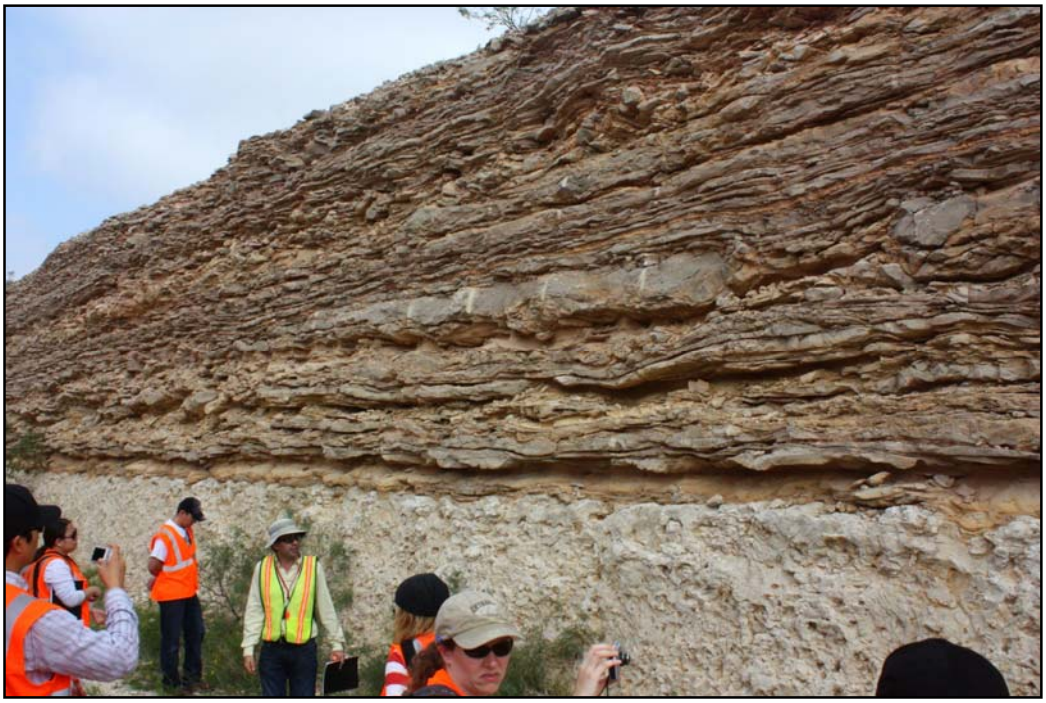
Modern Formation Evaluation



Formation Evaluation: let us not forget why we do well-log interpretation!

- Fluid Storage (Reserves)
- Speed of Flow (Permeability)
- Uniformity of Flow (Capillary Pressure and Relative Permeability)
- Production Decline with Time
- Recovery Factor
- Net-to-Gross
- Geomechanical/Completion Properties
- Seismic-Based Interpretation (aka Rock Physics)

Example: Eagle Ford Shale



Formation Evaluation

- Laboratory Physics/Petrophysics
- In-Situ Properties

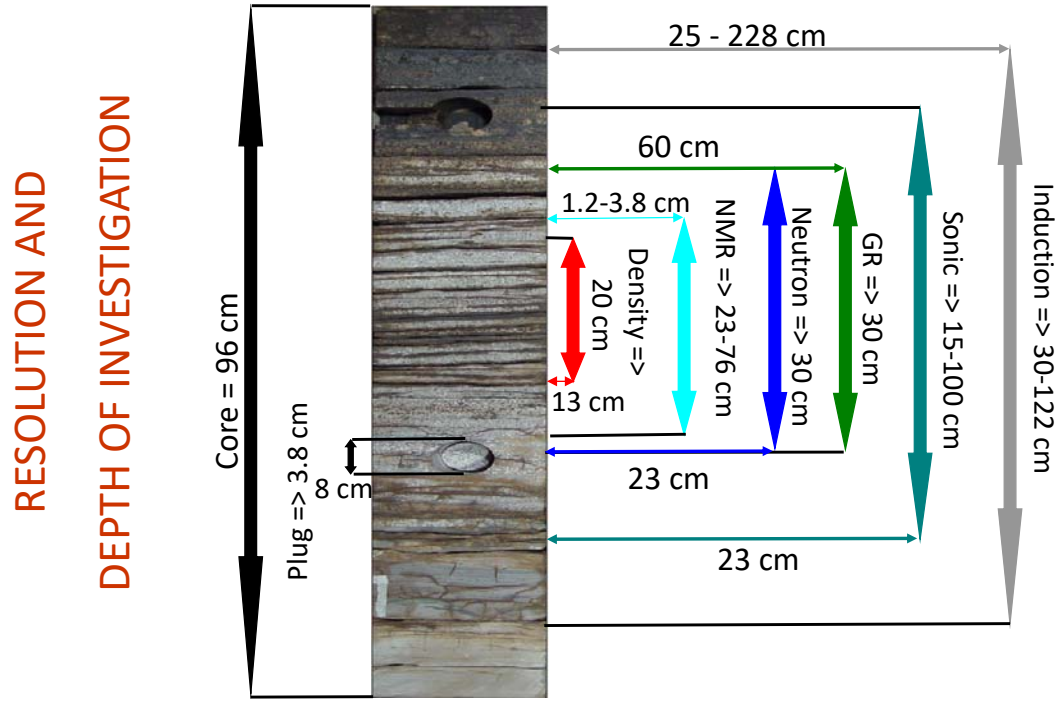
- Electrical conductivity, dielectric properties, magnetic properties
- Elastic properties
- Nuclear properties
- Magnetic resonance properties
- Pressure and fluid flow
- Fluid properties, electrolyte diffusion

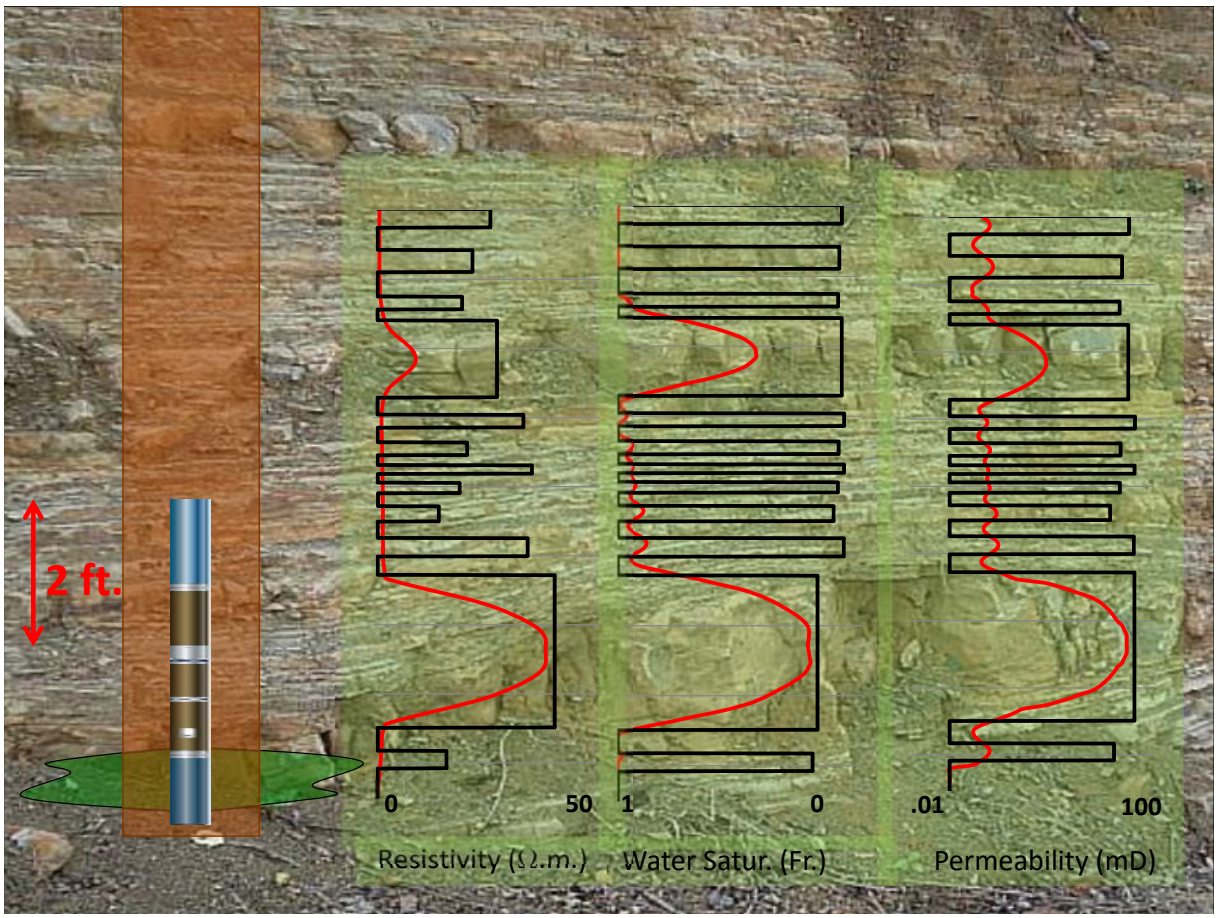
Physical contrast enhancement

Effective-medium properties of porous media

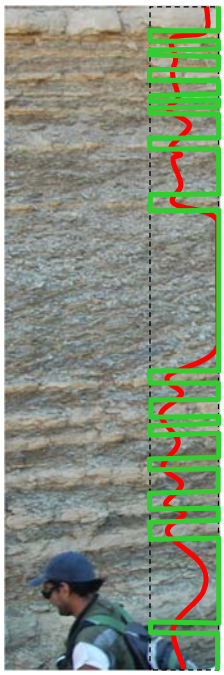
Different Tools:
Different Physics, Different Volumes of Investigation

Heterogeneity and Upscaling

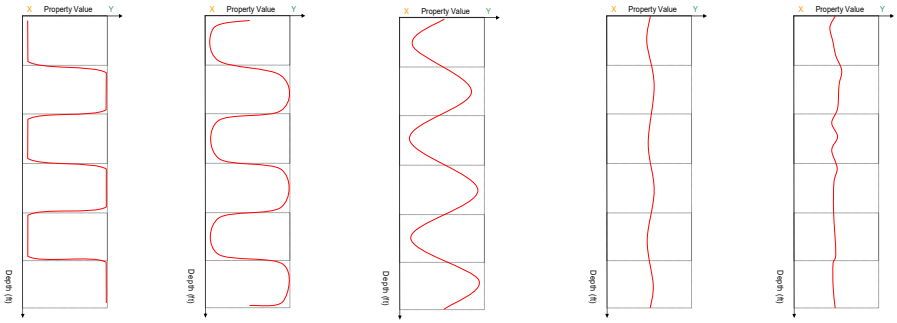




Bed-Thickness Effects on Well Logs (aka Shoulder-Bed Effects)

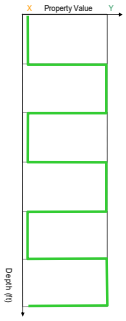


Baja California, thin-bedded sands

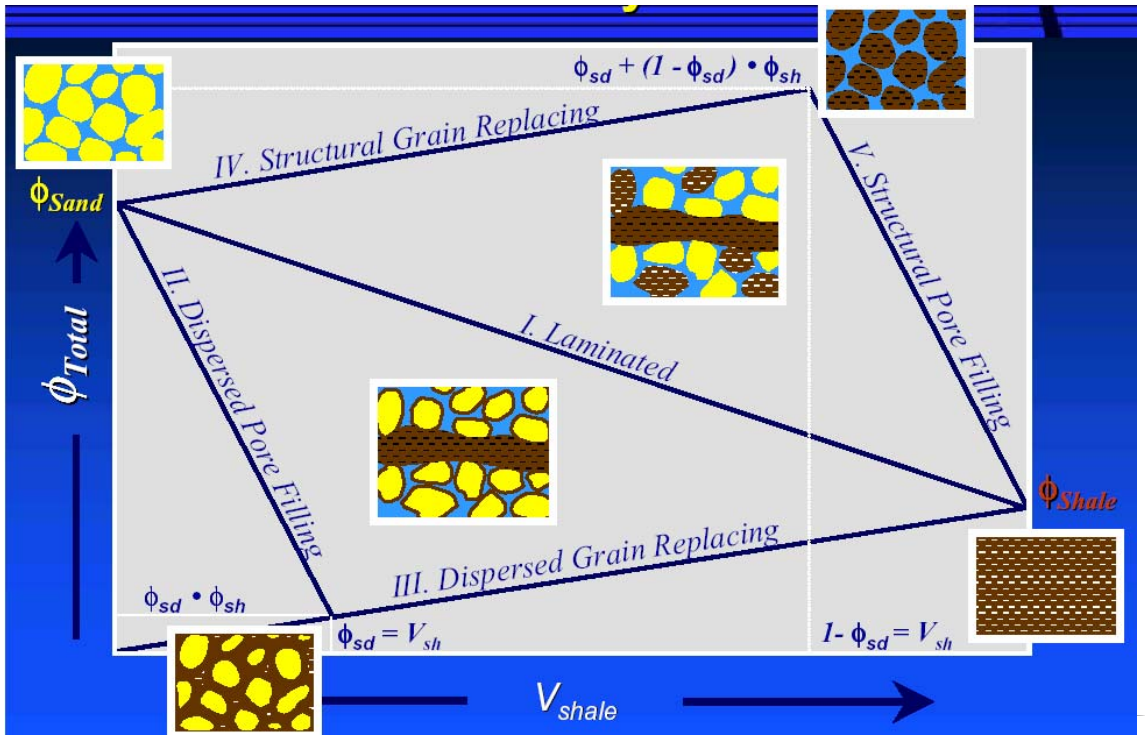


> 3ft | 1 to 3ft | 0.7 to 1ft | < 0.7 ft

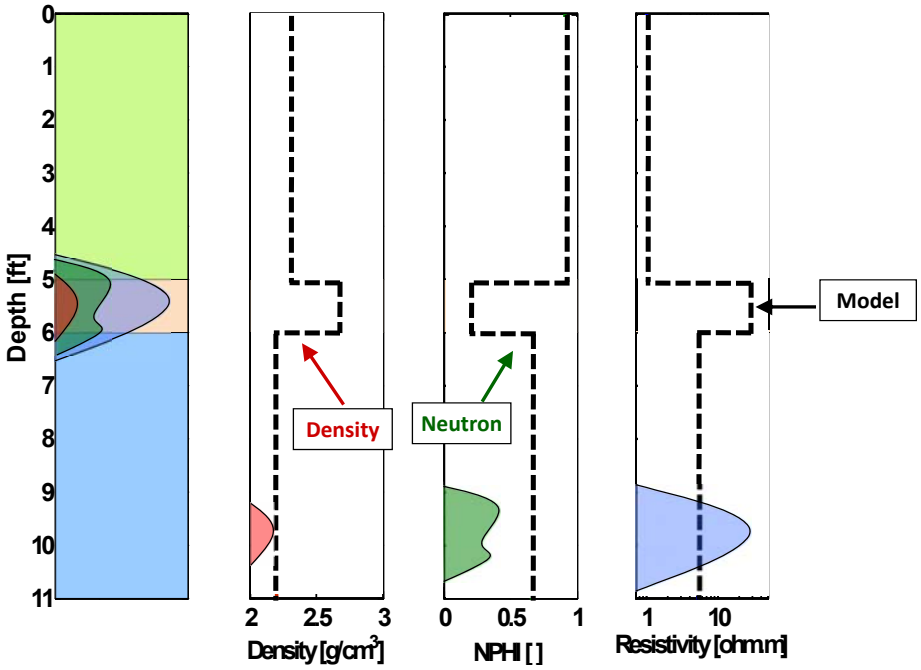
Actual Property Variation



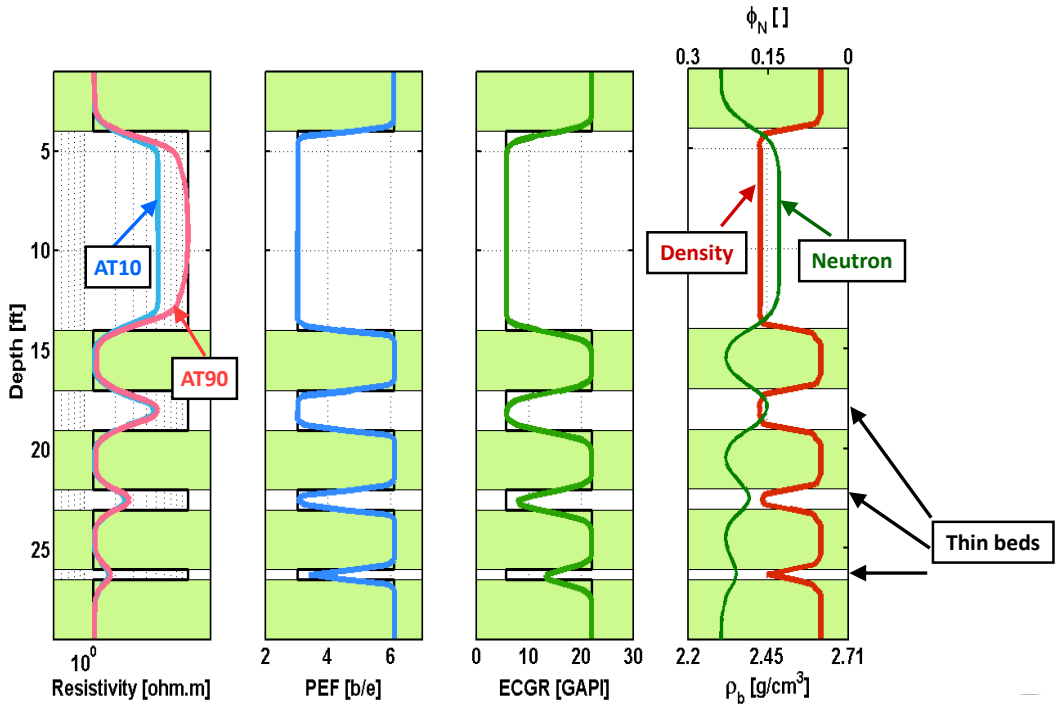
Thomas-Stieber Plot



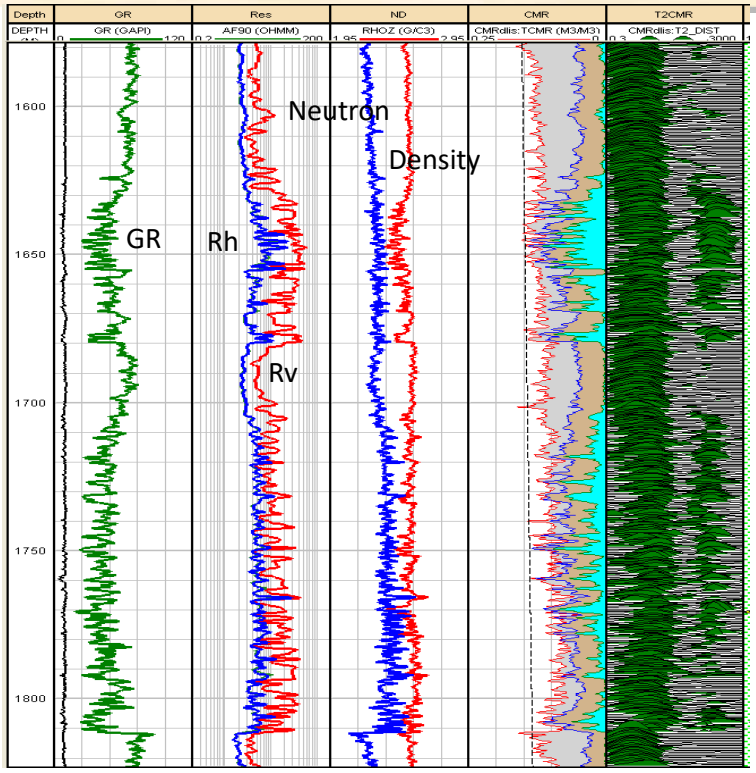
Uneven Vertical Resolution and Depth of Investigation



Thin-Bed Effects on Resistivity and Nuclear Logs



Example: Thin-Bed Effects on Resistivity and Nuclear Logs



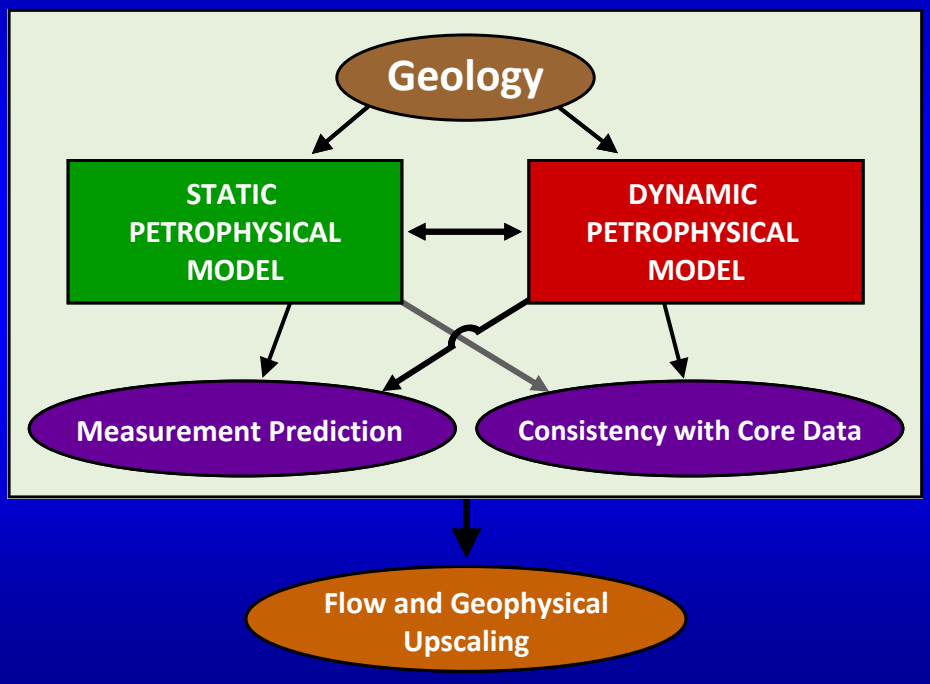
Remarks:

- Average value of logs per unit depth.
- Degree of oscillation of logs per unit length (energy).

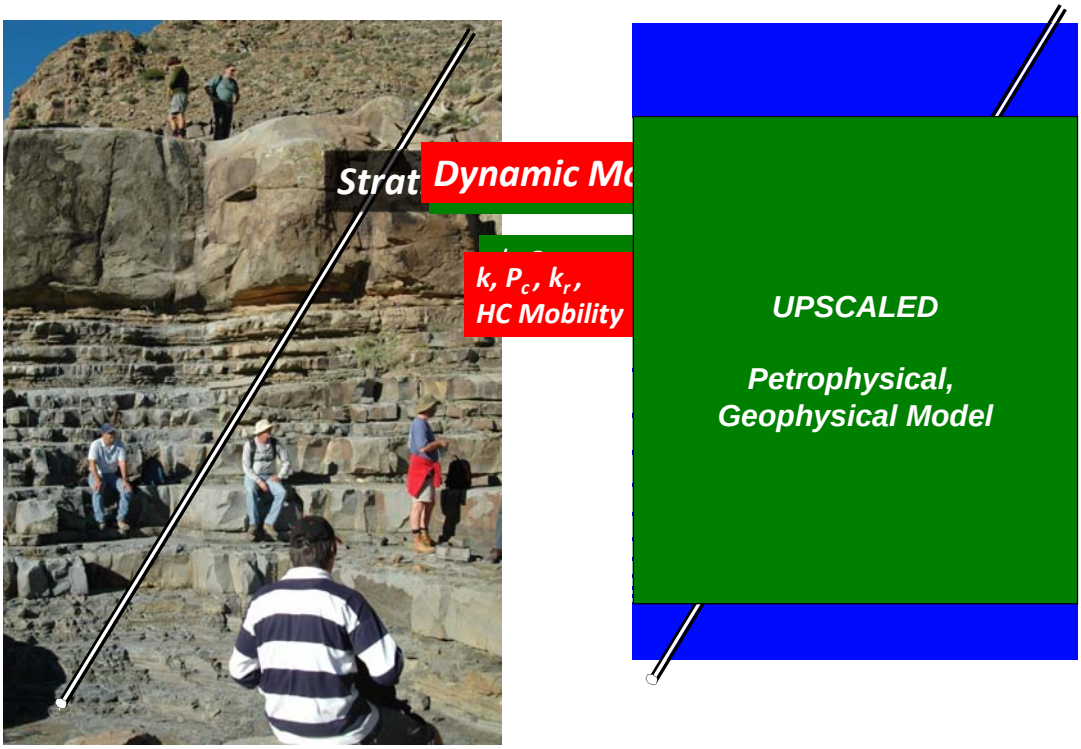
Rock Formations can be Quite Complex: Stramatolite Structure

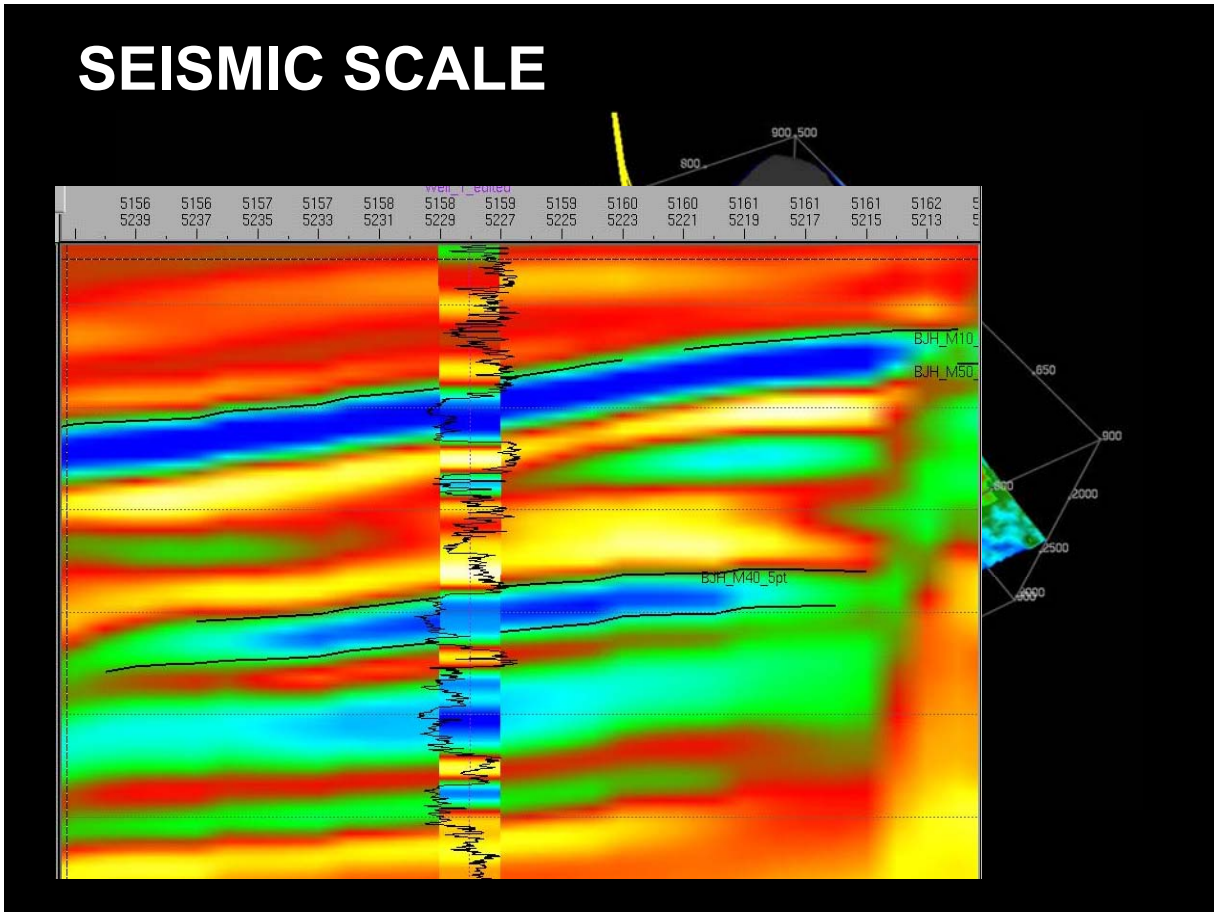
Examples of Variable Rock Heterogeneity

Modern Formation Evaluation

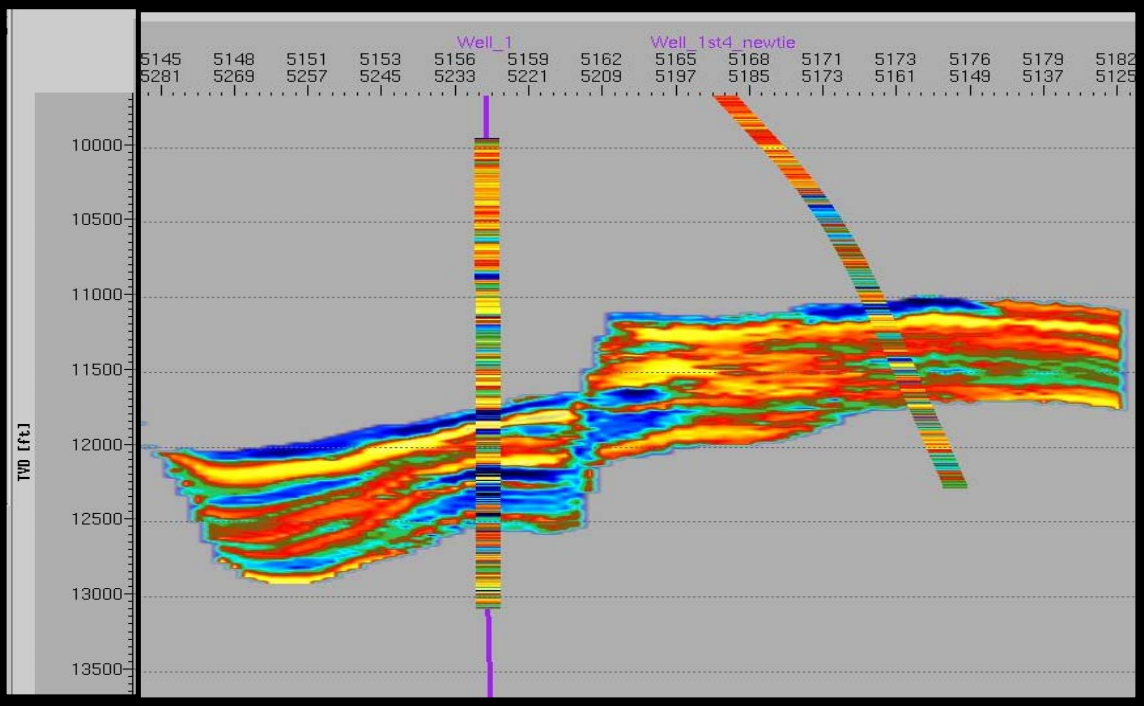


Static/Dynamic Stratigraphic Framework

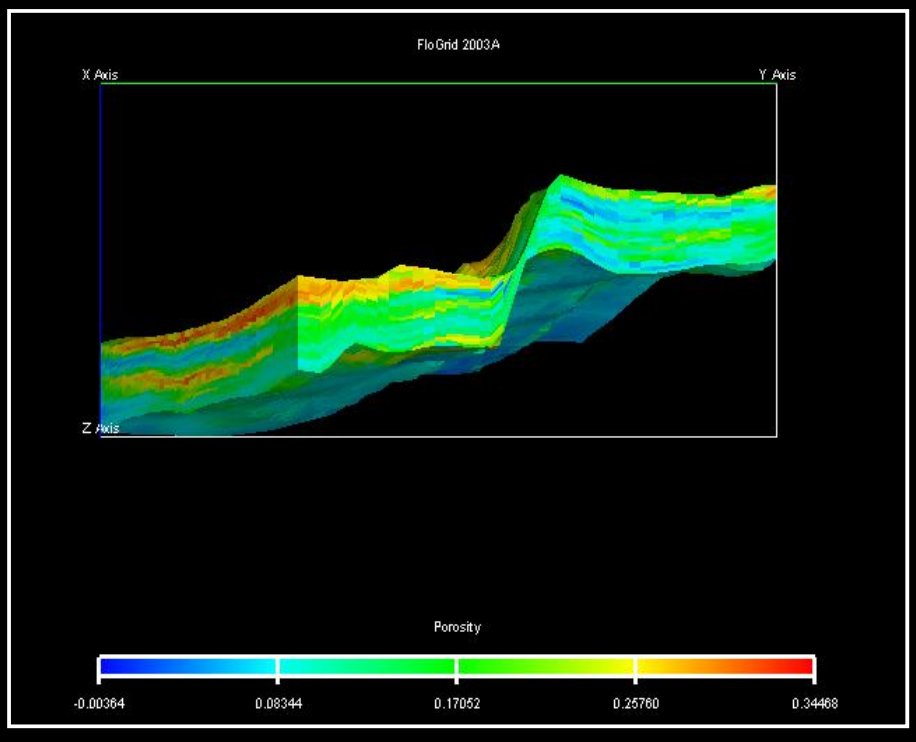




MULTI-WELL ANALYSIS



CONSTRUCTION OF RESERVOIR MODELS



UNDERLYING PEDAGOGICAL GUIDELINE FOR THIS COURSE

I hear and I forget.

I see and I remember.

I do and I understand.

不闻不若闻之，闻之不若见之，见之不若知之，知之不若行之。学至于行之而止矣。行之，明也。

Confucius Dictum

RULES (and lore) FOR THIS COURSE

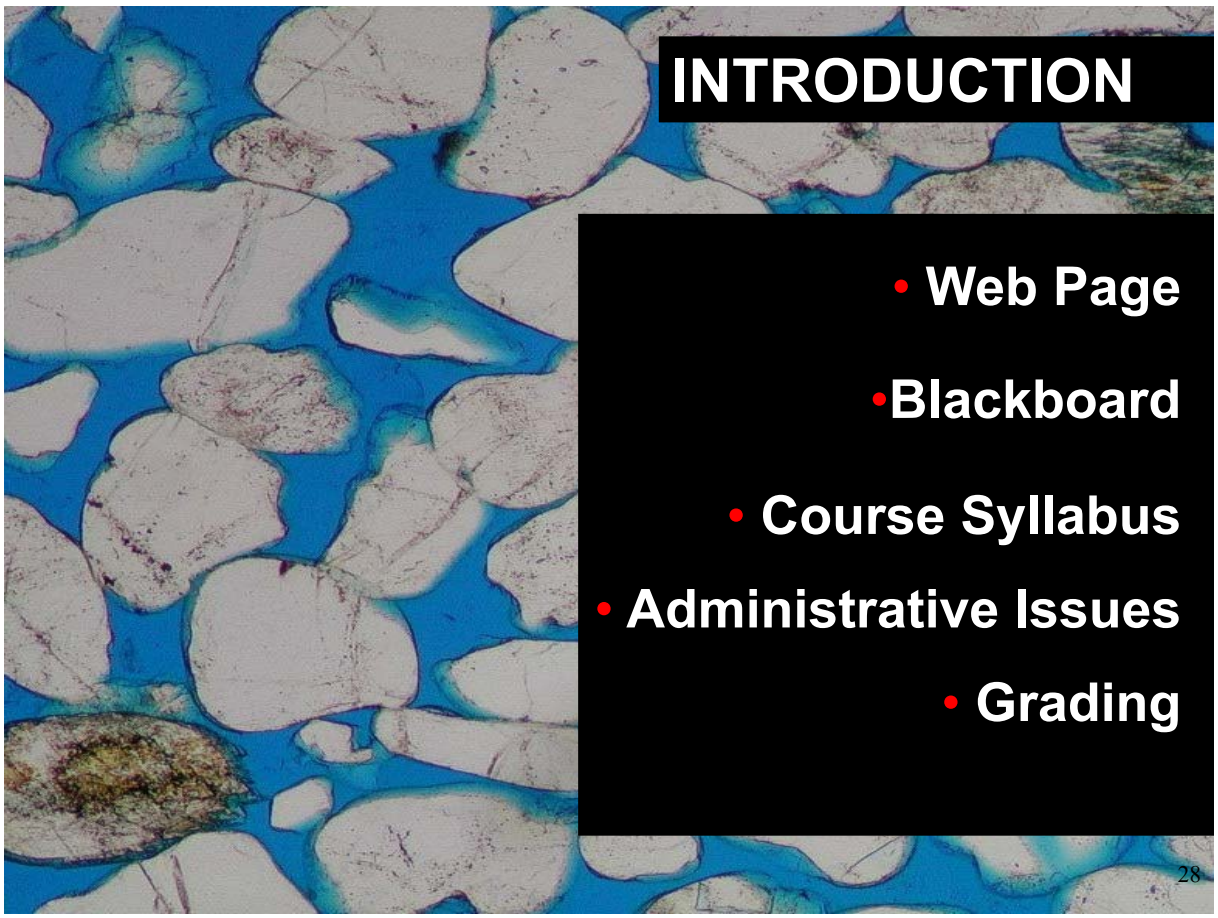
The Fundamentals:

1. Physics is King!
2. Geology is Queen!
3. Petrophysics is the Bishop!
4. INTEGRATION is the name of the game!
5. Well logging and formation evaluation are fun!
6. There are no stupid questions!
7. The instructor is here to INSTRUCT and to GUIDE students through their learning, not to deride them!
8. The instructor cannot guess that you need help!

MORE "SOCIAL" RULES FOR PGE385M

Respect earns respect:

1. Turn off your cell phones; do not text-message or web-browse in class!
2. If you feel like not coming to class, well … don't come to class! There are no prisoners in PGE385K!
3. If you come to class, please do not take trips in and out: this is not the country club!
4. If you come to class, avoid social and loud conversations; don't do homework for other classes during lectures.
5. Respect your peers' points of view and questions!



ADVANCED BOREHOLE LOGGING INSTRUMENTS:

1. Magnetic resonance
2. Dipole sonic
3. Borehole imaging
4. Formation tester
5. Elemental analysis
6. Logging-while-drilling (LWD)

ADVANCED INTERPRETATION TECHNIQUES:

1. Shaly sandstone analysis: Simandoux, dual-water, and Waxman-Smits
2. Multi-matrix volumetric analysis
3. Multi-matrix volumetric analysis and saturation
4. Fluid substitution analysis and elastic parameters
5. Integration of rock-core measurements
6. Magnetic resonance: irreducible water saturation, pore-size distributions, fluid typing, and carbonate petrophysics
7. Formation testing: in-situ pressures, mobility, and fluid properties.

MULTI-WELL INTERPRETATION TECHNIQUES:

1. Formation tops, sedimentary zonation, and petrophysical zonation
2. Litho-stratigraphic and chrono-stratigraphic correlations
3. Models of spatial continuity
4. Multi-well balancing techniques
5. Use of 3D seismic data
6. Inter-well interpolation techniques

Estimation of in-Place Hydrocarbon Reserves

Key Parameters:

1. Porosity, TOTAL and EFFECTIVE, ϕ_e
2. Moveable Hydrocarbon Saturation, S_{eh}
3. Thickness of Flow Units, Net Pay, Thickness (ft)
4. Areal Extent (Acreage), Area (acres)
5. Recovery Factor, R
6. Fluid Volumetric Expansion Factor at Surface Conditions, Exp

Reserves = [ϕ_e] x [S_{eh}] x [thickness] x [Area] x [R] x [Exp]

Units = STB [Stock-Tank Barrels]/7,758 (Oil)

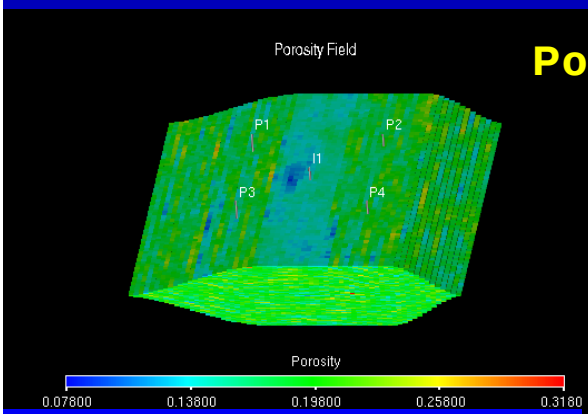
Estimation of Reservoir Producibility

Key Parameters:

1. Effective Porosity
2. Irreducible Water Saturation
3. Capillary-Bound Water
4. Absolute Permeability
5. Permeability Anisotropy
6. Capillary Pressure
7. Relative Permeability
8. Wettability
9. Pressure-Volume-Temperature (PVT) Fluid Properties
10. Wettability Alterations

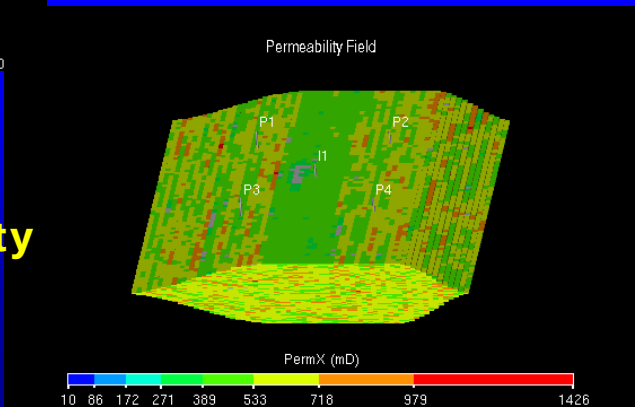
Remark: Most of these parameters are not available from well-logs; rock-core measurements and fluid samples are commonly used to estimate them.

Reservoir Simulation Model

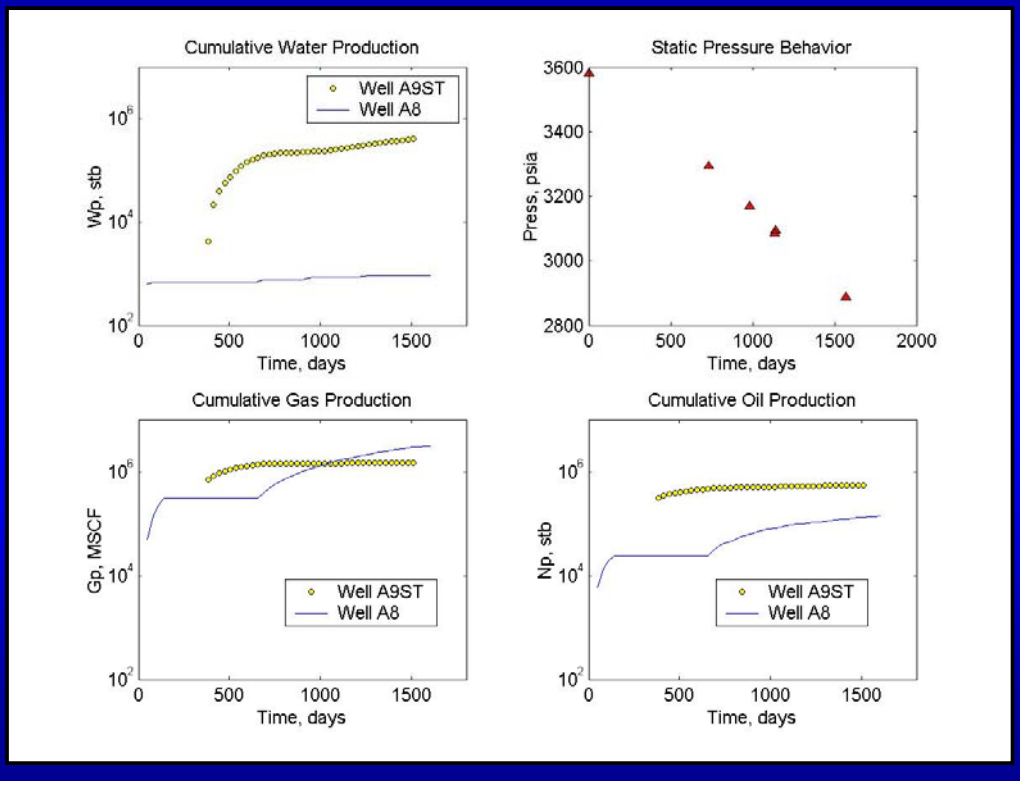


Porosity

Permeability



Production Data



WHAT FACTORS CONDITION THE DYNAMIC BEHAVIOR OF A RESERVOIR?

1. Is it the geological model?
2. Is it the petrophysical properties?
3. Is it the spatial distributions of petrophysical properties?
4. Is it the fluid-rock properties?
5. Is it the mobility of the fluids?
6. Is it the pore-pressure support mechanism?
7. Is it the PVT properties of fluids?
8. Is it permeable faults?
9. Is it the hydraulic communication of flow units?

RESERVOIR CONSODERATIONS: STATIC and FLOW-RELATED

1. Spatial Continuity of Flow Units
2. Spatial Continuity of Petrophysical Properties
3. Spatial Continuity of Fluids
4. Pore Pressure Support
5. Sweep Efficiency
6. Hydraulic Compartmentalization
7. Optimal Placement of Development Wells
8. Optimal Regulation of Fluid Production Rates
9. Water Production
10. Variable Hydrocarbon Prices and Production Costs
11. Management of Uncertainty!

Reservoir Characterization: FAST TRACK

Sequential Steps (I):

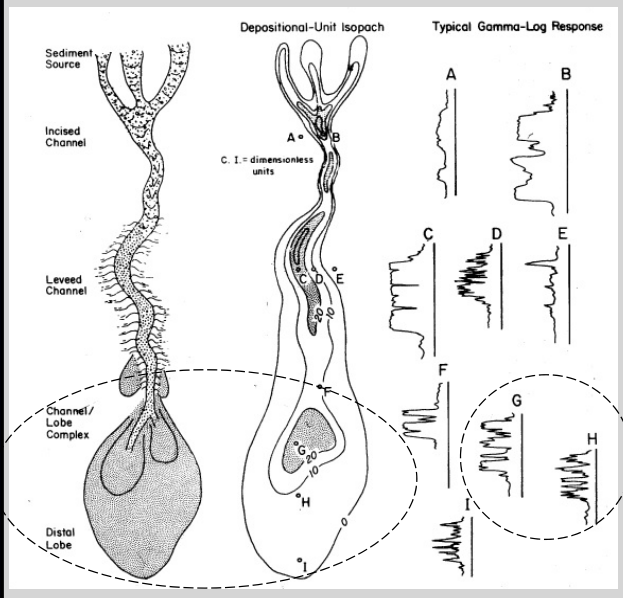
1. Quality Control of Well Logs, Integration of Rock-Core Data and Well Logs: Estimation of total and effective porosity, total and effective saturation, and permeability.
2. Assessment of Flow Units. Rock Classification. Lorenz Plots. Effective Horizontal and Vertical Permeability. Capillary Pressure and Relative Permeability Analysis.
3. Well-to-Well Correlation. Geological Model.
4. Seismic Petrophysics. Feasibility Analysis. Attributes. Post- and Pre-Stack Seismic Amplitude Inversion. Well-to-Well Correlation. Geological Model.
5. Refine Rock and Flow Unit Classification. Refine Petrophysical Analysis. INTEGRATE!

Reservoir Characterization: FAST TRACK

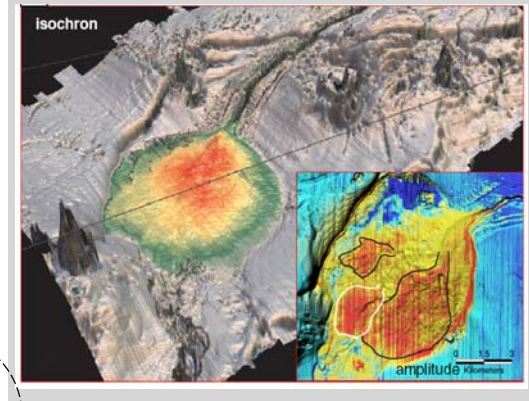
Sequential Steps (II):

6. Construct Cellular Reservoir Model. Geostatistical Construction with or without Seismic Amplitude Data: Flow Units, Facies, Petrophysical Properties. Initial Fluid Distribution: enforcement of capillary equilibrium.
7. Construct Tank (Homogeneous) Reservoir Model. Enforce Mass Balance and PVT Properties. Assess Pore-Pressure Support Mechanisms.
8. Simulate Dynamic Fluid Production and Pressure Depletion. Compare to Production Measurements.
9. Sensitivity Analysis. Experimental Design.
10. Uncertainty Analysis. Error Bounds.
11. Rank Production-Controlling Mechanisms.

Geological / Depositional Model



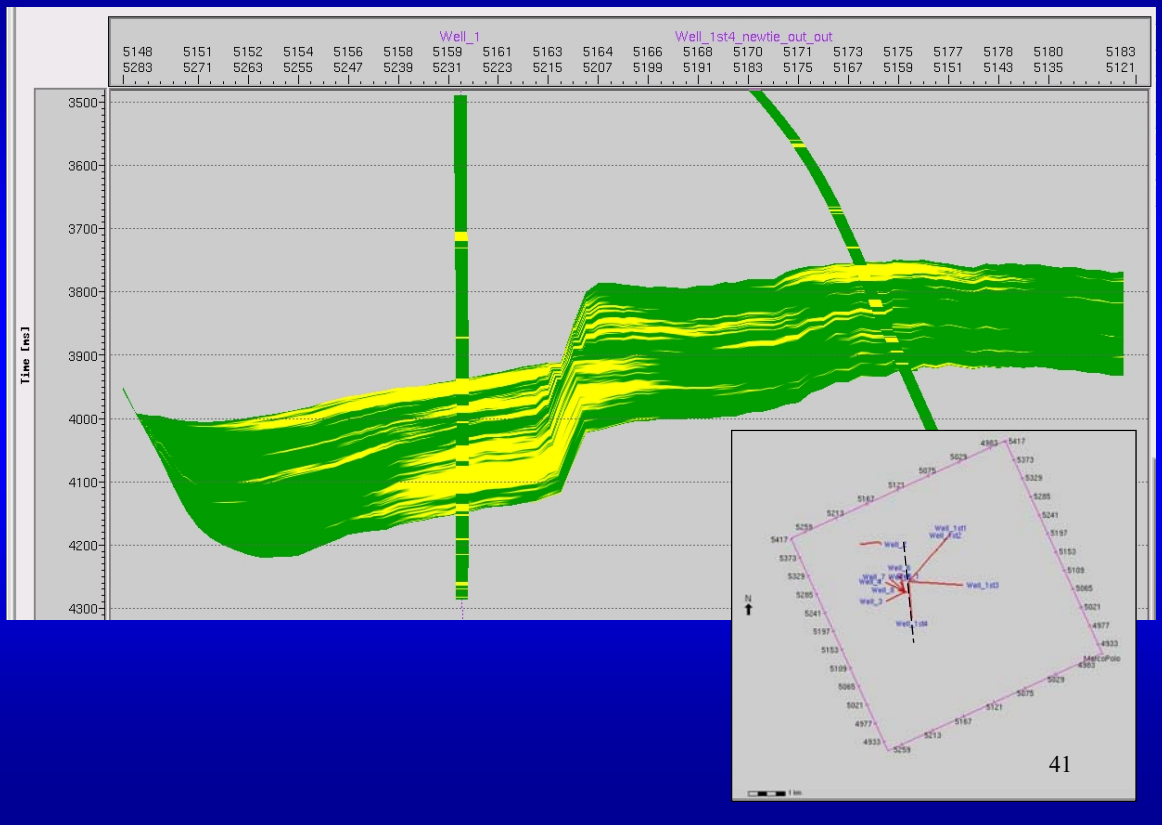
Dr. Galloway's model



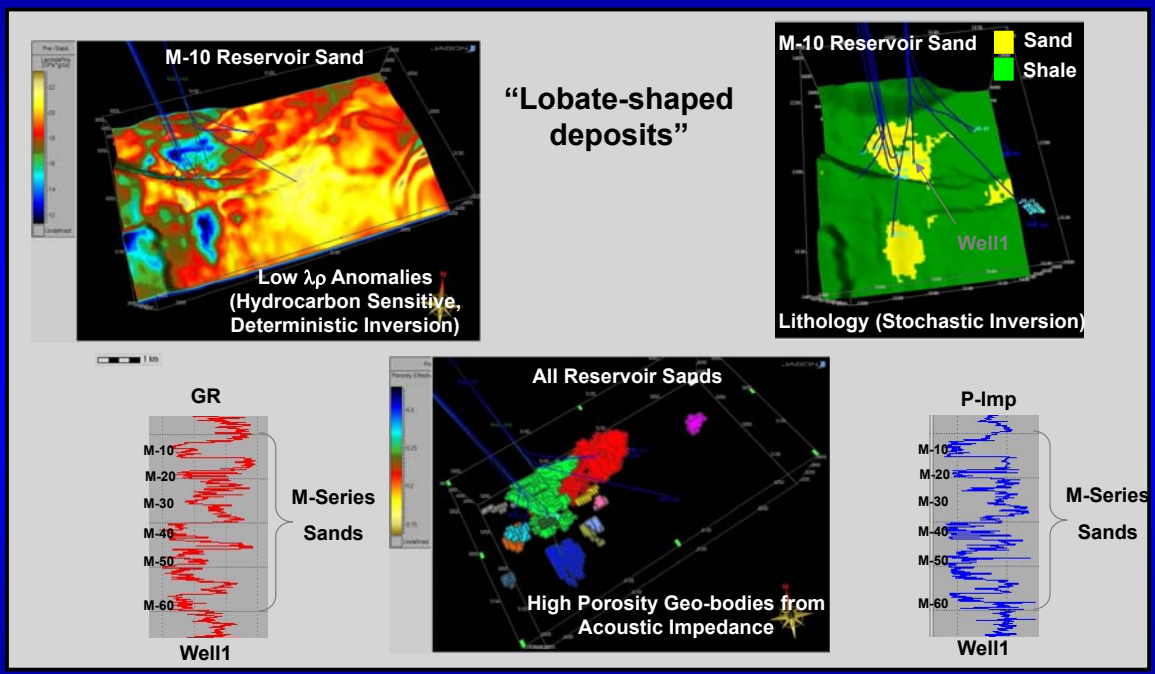
Analogous Example: Offshore Nigeria, Niger Delta Slope

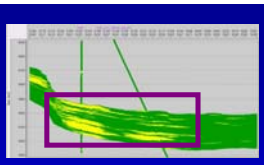
From Pirmez et al., 2000

Integration of well logs with 3D pre-stack seismic data

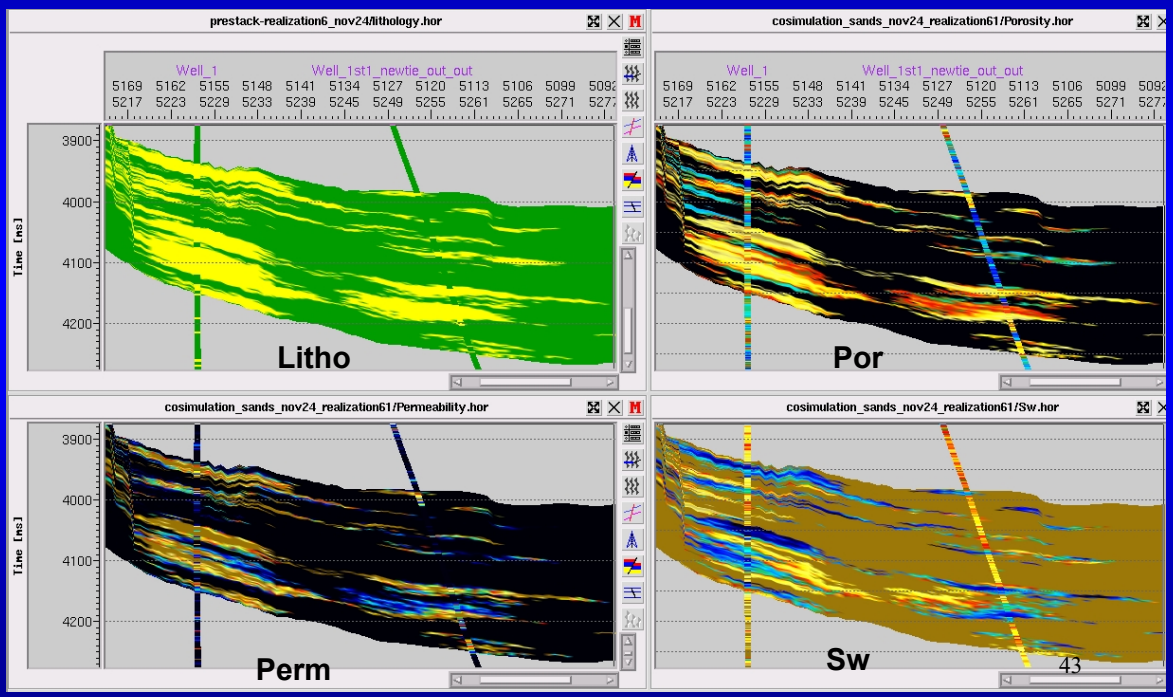


Measurement Integration



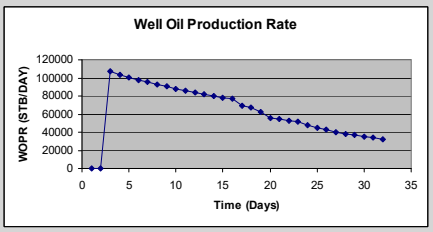


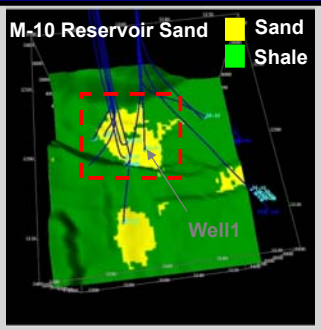
Petrophysical Properties



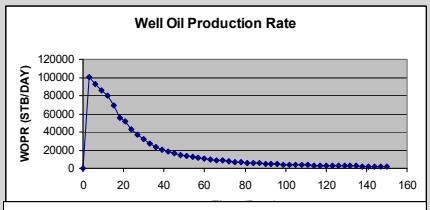
Fluid-Flow Simulation (Oil Production Rate)

1 Month

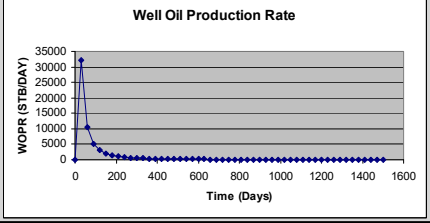


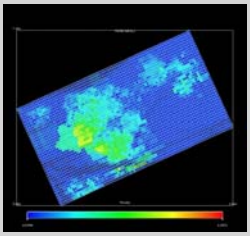


5 Months



4 Years





Reservoir Characterization: REFINED STRATEGY

Sequential Steps (I):

1. Global Correction and Calibration of Well Logs.
2. Petrophysical Properties of Well Logs and Rock-Core Data Fully Integrated with Geological Model. Assessment of Rock Types and Flow Units.
3. High-Resolution Processing of Seismic Amplitude Data, Post- and/or Pre-Stack. Seismic-Well Log Ties. Refined Post- and/or Pre-Stack Inversion. Refined Time-Depth Conversion. Integration with Geological Model.
4. Well-to-Well Correlation of Flow Units and Petrophysical Properties. Integration with Geological Model. Integration with Inverted P- and/or S-wave impedances.
5. Assessment of Uncertainty and Error Bars.

Reservoir Characterization: REFINED STRATEGY

Sequential Steps (II):

6. Construction of Cellular Reservoir Models. Refined Upscaling Strategies. Assessment of Numerical Errors. Comparison against Tank Model.
7. Sensitivity Analysis. Pore-Pressure Support Mechanisms. Fluid PVT properties. Explore compartmentalization. Experimental Design.
8. Uncertainty Analysis of Fluid Production and Pressure Depletion.
9. Optimal Placement of Step-Out and In-Fill Wells.
10. History Match and Feedback Loop for Refinement of Static and Dynamic Reservoir Models.

GOALS AND EXPECTATIONS

1. Shaly-sandstone models to estimate porosity and hydrocarbon saturation.
2. Permeability assessment and rock classification.
3. Controls exerted by capillary pressure and relative permeability on rock producibility.
4. Use of magnetic resonance measurements for petrophysical/fluid assessment.
5. Use of formation-tester measurements to assess fluid pressure and mobility.
6. Saturation-height analysis and pressure-gradient estimation.
7. Borehole imaging, principles and interpretation.