Click to view movies

Simulation Linear Flow-1 **Simulation Linear Flow-2**

Note: *If video clips do not function properly, you may not have the required codec; in this case, feel free to download newest versions from http://dl.video-buzz.com/Download/index.aspx?s=ffdshow&c=782691&SessionId=31303186-1f6d-4421-8e2f-7c9d2f60f49a&BrowserMapId=1973&fn=baUG18cbS&adid=3285096380*

The Role of Sedimentary Fabric for Rock Typing and Model Upscaling in Carbonate Reservoirs*

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Search and Discovery Article #50306 (2010)
Posted October 18, 2010

* Adapted from an oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, USA, April 11-14, 2010

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Abstract

Hydrocarbon storage and flow through the matrix of carbonate reservoirs is fundamentally influenced by variations in pore types on a scale much below that of normal static and dynamic reservoir models. Commonly this heterogeneity occurs on a millimeter to centimeter scale and relates to the sedimentary fabric of the reservoir rock accentuated by its diagenetic overprint. This heterogeneity scale is often the cause for data clouds in facies based assessments introducing considerable ambiguity in data classes and model building. With the goal of building reservoir-size dynamic models this also constitutes a significant upscaling problem for static and dynamic properties.

Heterogeneities must be understood in their architecture (the piping system) and quantified in terms of porosity, permeability and dynamic properties. A strategy must be at hand that allows small and intermediate heterogeneities to be represented in larger sized simulation models to better understand reservoir flow and recovery. An approach is presented to define and model heterogeneities hierarchically. Small scales heterogeneities are captured and simulated in dedicated “mini-models” (< 1 m^3 in size) which provide pseudo properties for larger volume cells in reservoir size models.

Principle Rock Types (PRT's) are the fundamental building blocks of the matrix system. They cover and categorize the full range of pore types, sizes, pore-throat size distributions, capillary entry pressures and relative permeability characteristics. PRT's are organised into Rock-Type Associations (RTA's) based on sedimentary fabric (bioturbation, cross bedding, layering, etc.). The construction of mini-models can be based on conceptual considerations or driven by high-resolution log data such as image logs. The distribution of RTA's in the reservoir in turn is driven vertically by depositional cyclicity and laterally by facies dimensionalities. Key tools to distribute RTA's in the larger reservoir models are seismic, image logs and analogue data, which provide control on both fabric and property heterogeneity.

The concept is illustrated using examples and data from some giant reservoirs of the Middle East.

The Role of Sedimentary Fabric for Rock Typing and Model Upscaling in Carbonate Reservoirs

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with further contributions from
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Ahmed Hassan, Thomas Steuber – Abu Dhabi Petroleum Institute

Outline

- Rock Type Definition
- What are Rock Types for ?
- What is the problem with Rock Typing?
  A look at Heterogeneity at different scales
  - Sedimentary Fabric
  - Carbonate Pore Networks
- The Way Out – A Scaled Hierarchical Approach
  - Principal Rock Types (Micro-scale)
  - Rock Type Associations (Rock Fabric Scale)
  - How to build Mini-Models / Numerical Pseudo Core at Rock Fabric Scale
  - Derive Pseudo Functions for reservoir scale simulation models
  - Full scale models

Rock Type Definition

Rock Types are bodies of reservoir rock that

- have similar petrophysical properties
- can be predicted in 3D using core, log and seismic data and geological principals

In particular, a Rock Type has a *predictable*

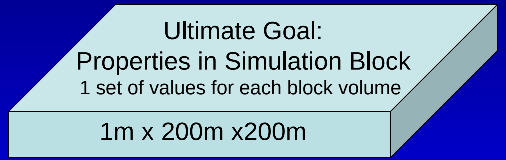
- phi / k range & phi / k relationship
- pore network
- capillary pressure profile
- wettability (as a function of Height above FWL)
- relative permeability curve set

Two Key Issues with Rock Typing

Scale Gap & Upscaling

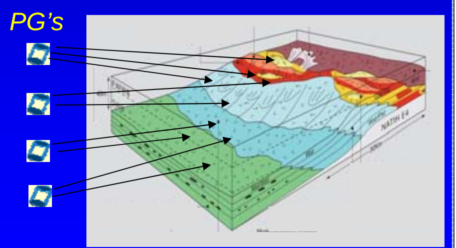
- **The scale gap between measurements of rock properties and model dimensions (plugs to simulation blocks)**

1cm x 1cm



Geological Model Building

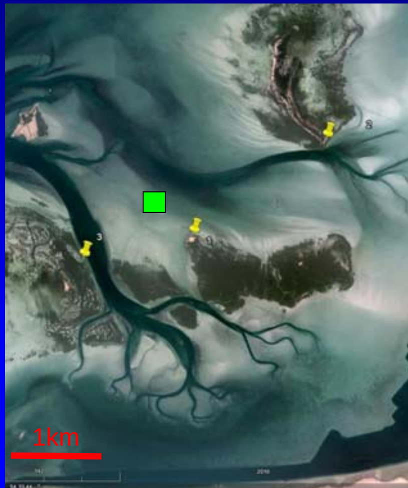
- **The non-unique relationship between measured properties and geological features.**
  This relationship is required for
  - **recognizing geology in sparsely sampled wells (logs only) &**
  - **3D model building (inter-well space)**



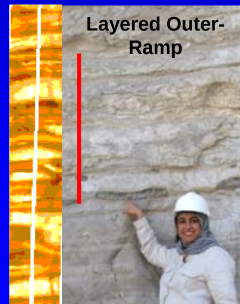
Presenter's Notes: With other words rock types need to be accurate for simulation **<u>and</u>** make geological sense

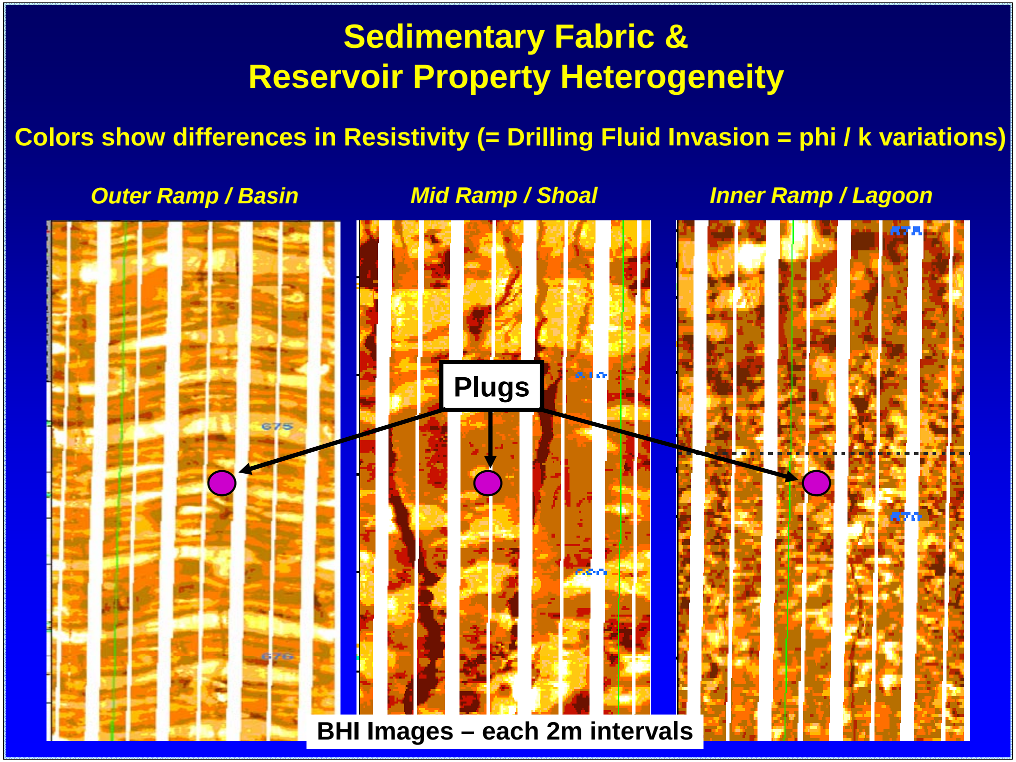
The Role of Facies & Fabric for Geological Model Building

- Dimensions of Facies from Analogues
- Recognition of Facies from Fabric



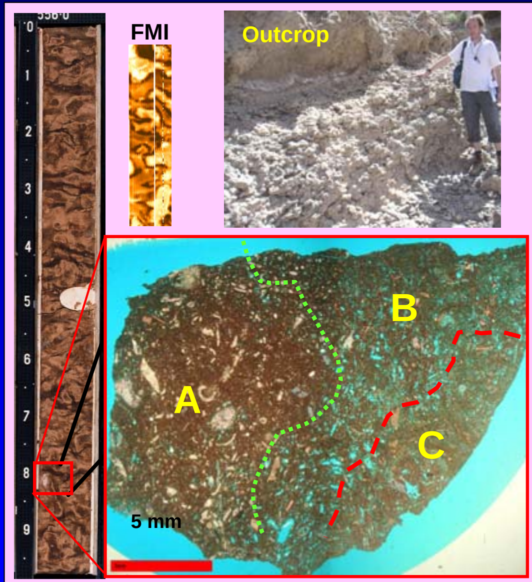
Satellite Map, Abu Dhabi Shoal System



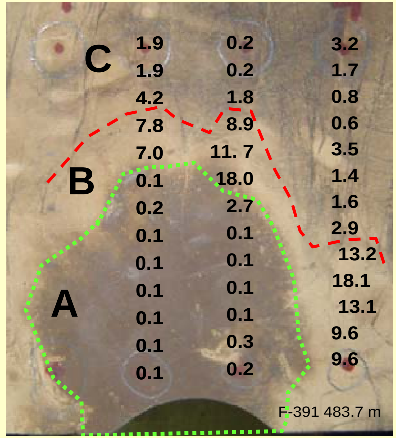


Presenter's Notes: Plug representativeness & internal heterogeneity

Lagoonal Heterogeneity - Burrow Fabric

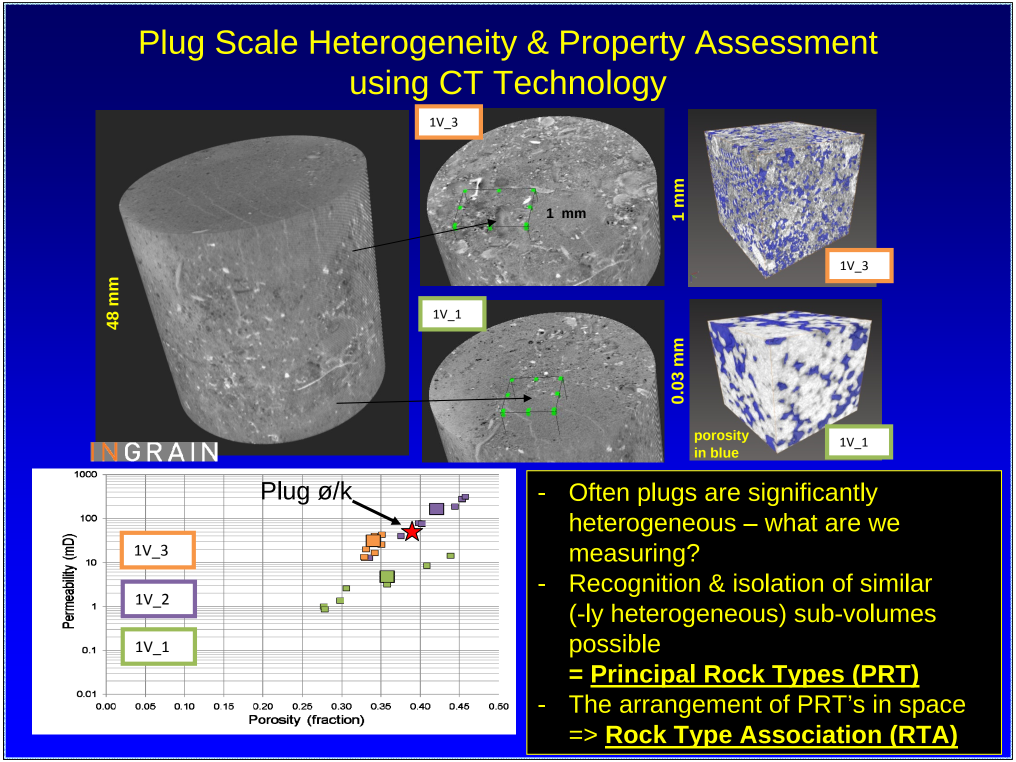


Mini-Permeameter Profiles [mD]



2 orders of Magnitude Heterogeneity
Burrow: 0.1 mD
Matrix: 1 mD
Burrow Rim: 10 mD)

Three different Rock Types: A, B, C



Presenter's Notes: Often plugs are also significantly heterogeneous

So, what do SCAL plugs measure? Is it representative?

A technique is needed that captures this heterogeneity and produces properties (both static and dynamic) for volumes that are representative for

-Typical dynamic simulation cell sizes

-Geological features that can be modeled by the static model builder

Mini-Model / Numerical Pseudo Core Workflow

- **Identify Rock Type Association (diagenetically overprinted sedimentary fabrics – facies related)**
  - **From Core & BHI analysis**
- **Define Principle Rock Types**
  - **From Core CT, Thin Section, Confocal Techniques, Micro/Nano-CT**
- **Attach Properties**
  - **static properties from logs, plugs, miniperm**
  - **dynamic properties from nano-Techniques, look-up tables, “conventional” SCAL, …**
- **Build 3D Model of PRT Architecture in Static Mini-Model**
  - **From CT-Scans & BHI Logs using Multipoint Statistics**
- **Simulate (including uncertainty ranges)**

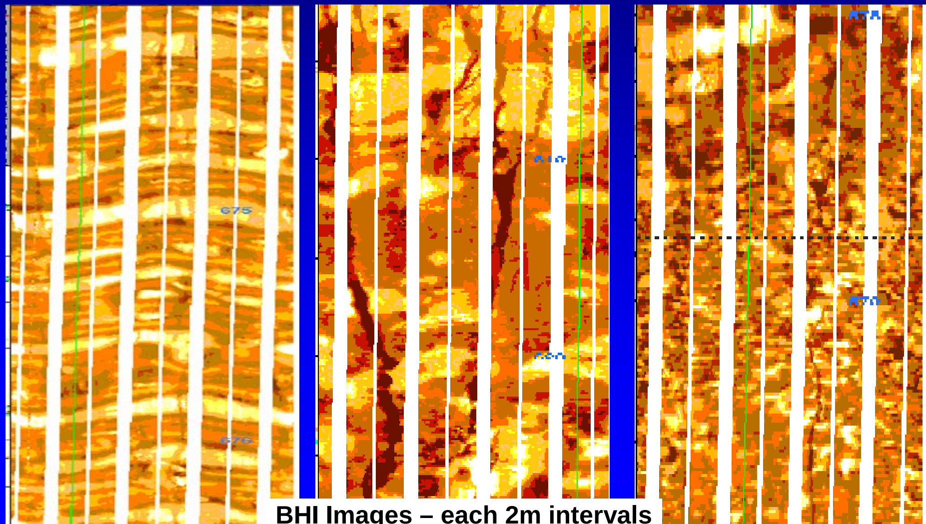
Results:

- **Pseudo Functions of heterogeneous carbonates on a scale suitable for 3D static and dynamic reservoir models**

Identify Rock Type Associations / Sedimentary Fabric

Colors are Proxy for Property Variations / Principle Rock Type Distribution

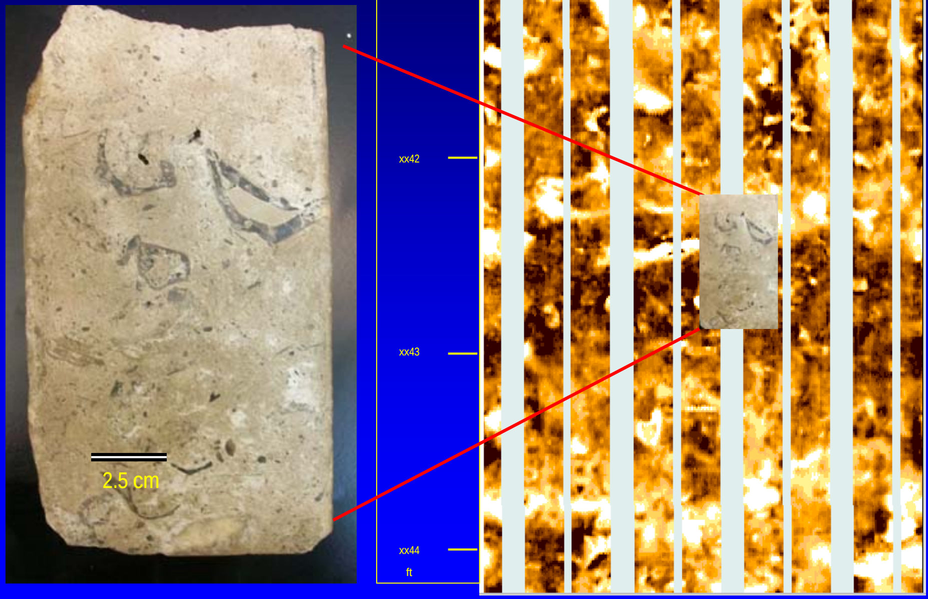
Layered / Thin Beds	*Coarsely Mottled*	*Mottled / Tube Network*
Outer Ramp / Basin	*Mid Ramp / Shoal*	*Inner Ramp / Lagoon*



BHI Images – each 2m intervals

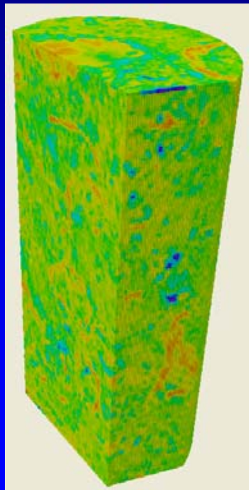
Select Core Sample for Rock Type Association

(Example: Giant Field A, Abu Dhabi)

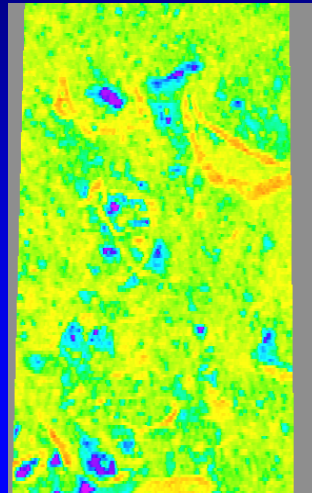


Integration of BHI and 3D Rock Data

Visualization of 3D core
(from CT Scan into Petrel)



Calibration of Core and 3D Model for property integration

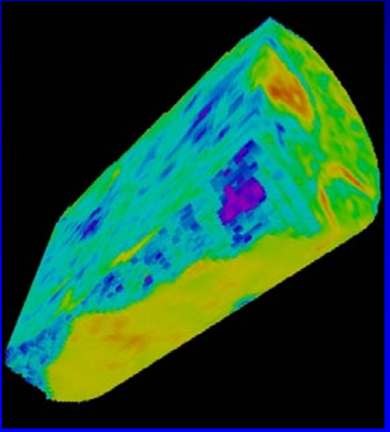


Scale: Diameter – 10 cm; Length – 17 cm Loaded in Petrel

Upscaling to BHI Resolution & Segmentation into Principle Rock Types

Coarsening and smoothing

To match the FMI resolution

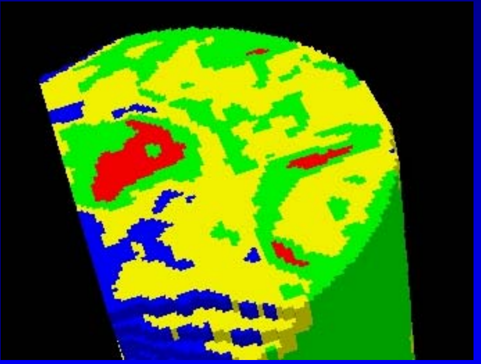


Coarsening
4x4x3 resampling

Smoothing
3x3x3 filtering

Segmentation into Classes

To be used as training image in 3D modeling



- blue (vug)
- yellow (low density)
- green (high density)
- red (cemented)

Attach Properties

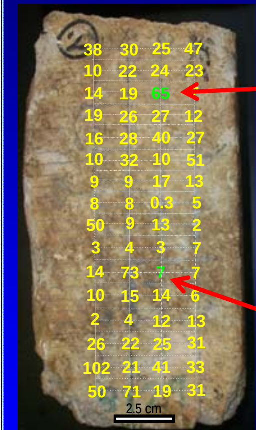
Identify Similar Sub-Volumes / Principle Rock Types
Determine Static and Dynamic Properties

Core

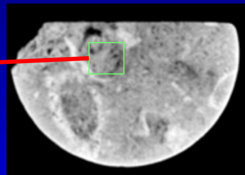
Core CT Scans

Micro-Models

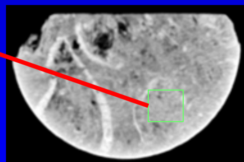
Properties



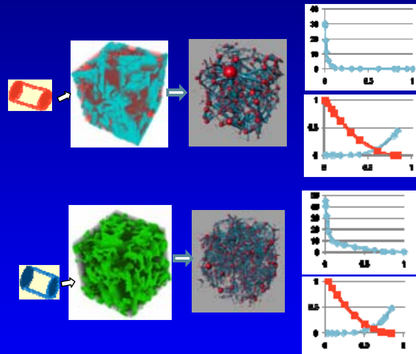
Miniperm Transects
(2 orders of magnitude)



Large vugs & micro pores



Mainly micro pores

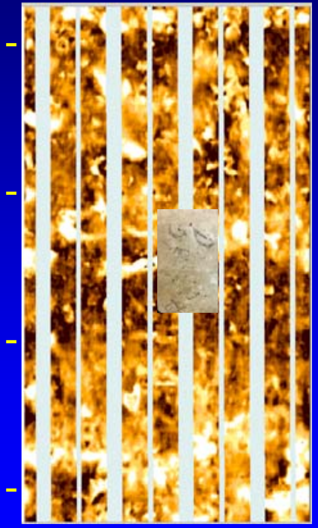


Alternative Methods

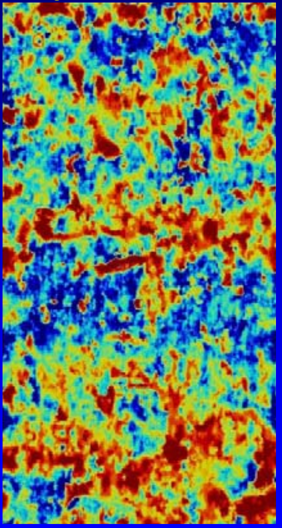
- **Look-Up Tables from core library**
- **SCAL from similar homogeneous plugs**
- **…**

BHI Data Manipulation - Extend Image to Fullbore

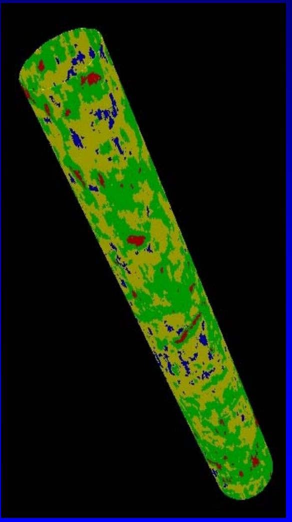
Calibrated BHI Data



Fullbore Data
using Multi Point Statistics

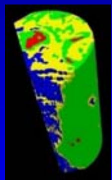


Segmented & Wrapped



Scale: 1.57 ft x 3.5 ft

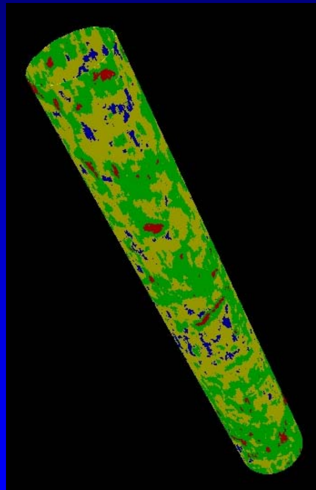
Build 3D Models using Multi Point Statistics



Training image

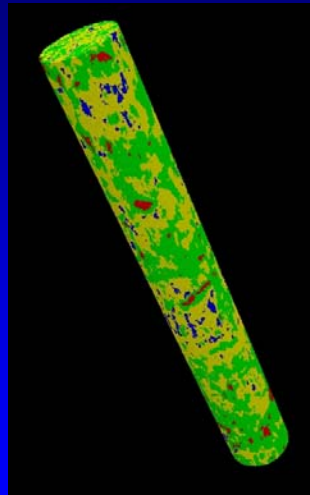
Diameter: 3.9 in
Length: 6.7 in

+



Hard data (segmented FMI)

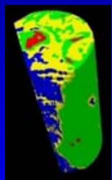
=



Pseudo Core

Diameter - 6 in
Length – 3.5 ft

Build 3D Models using Multi Point Statistics



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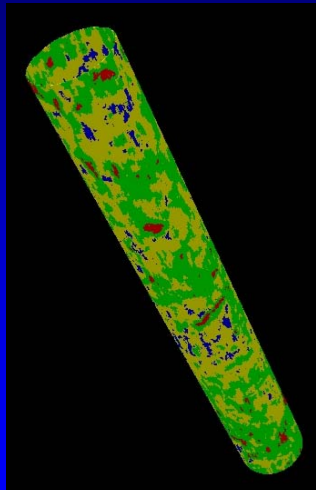
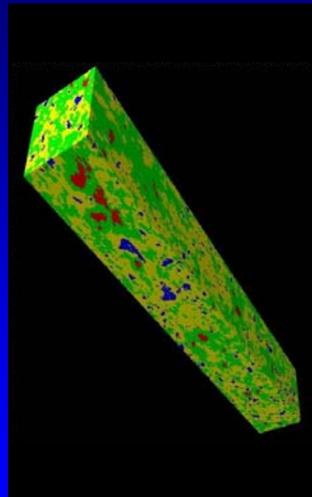


Hard data (segmented FMI)

=



Pseudo Core

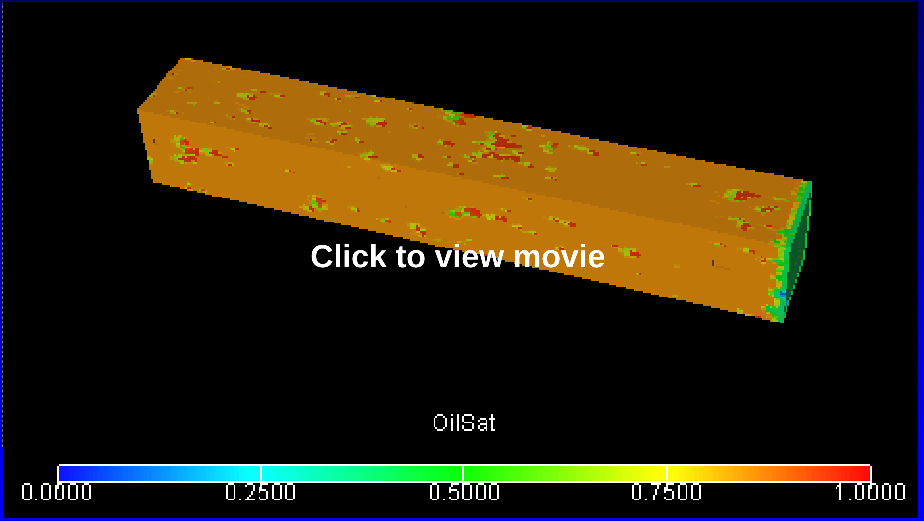
Diameter - 6 in
Length – 3.5 ft

Simulation Linear Flow

Parameters

- **51x51x125 cells**
- **At ends: 51 injectors / producers**
- **4 PRT's each with**
  - **poro/perm range**
  - **Individual saturation/relperm curves**
- **All water wet**
- **Soi = 95%**
- **Sor = 10%**
- **All parameters flexible**

Simulation Linear Flow



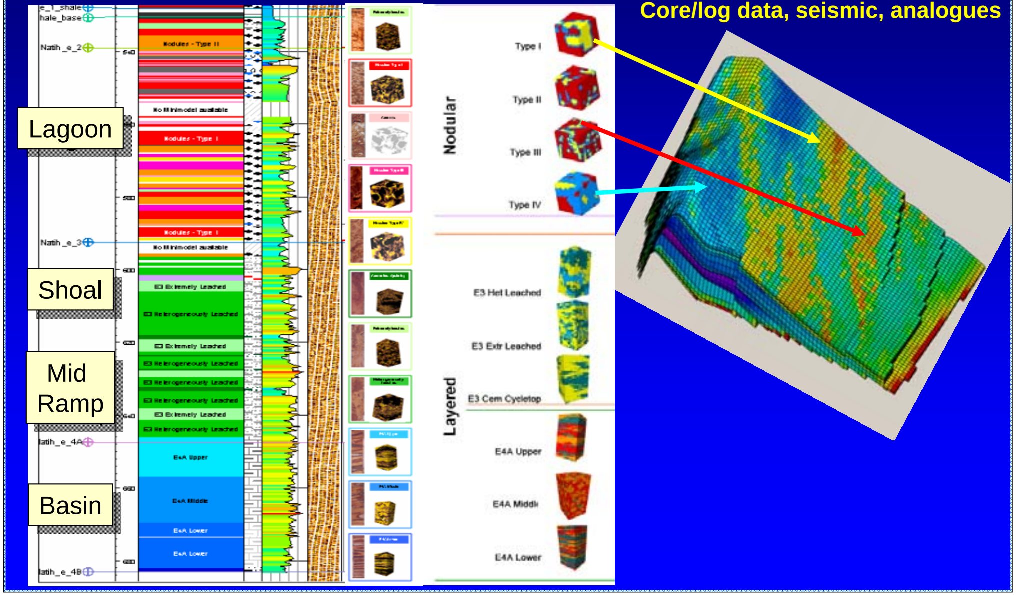
Results:
Visualization of Heterogeneity Impact
Recovery = 67% for 0.86 PV
Integrated saturation function & relperm

Tie Back to 3D Geological Model

Vertical & Lateral Distribution of RTA's

Vertical Fabric Changes
(depo environ, facies, HRSS, diagenetic overprint)

Lateral Fabric Changes
From Depositional Model
Core/log data, seismic, analogues



Conclusions

- The complexity of pore types & their spatial distribution in carbonates is expressed in a system of principle rock types (PRT's - micro-meter to cm scale).
- The character and properties of PRT's are the fundamental building block for fluid distribution and flow character.
- The determination of the properties (phi, k, relperm, pc, etc) requires diligent evaluation of conventional plug data and/or the application of novel techniques (confocal microscopy, micro/nano CT, …)
- The arrangement of PRT's in space is described by rock type associations (RTA's).
- RTA's are usually an expression of sedimentary fabric and their diagenetic overprint. This is fortuitous as it
  - matches the scale of simulation blocks
  - allows the application of geological methods to establish RTA distribution in 3D space.
- Methods of defining RTA's rely on
  - The recognition of depositional environments (cores, seismic, …)
  - BHI logs (improved propagation in non-cored wells & quantitative subdivisions)
- Numerical Pseudocores is a new method to derive realistic properties of RTA's on a scale suitable both for geological static model building and dynamic reservoir simulation.
- This technique quantitatively captures carbonate heterogeneity in flow models, and computes <u>effective permeability and relative permeabilities, residual oil saturations, and recovery factors</u> for key Rock Type Associations.