Results and Methodology from ANH (Colombia) Unconventional Resources Core Project

Joel D. Walls[1], Juliana Anderson[1], Elizabeth Diaz[1], and Maria Rosa Ceron[2]

Search and Discovery Article #80346 (2013)**
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*Adapted from oral presentation given at Geoscience Technology Workshop, Revisiting Reservoir Quality Issues in Unconventional and Conventional Resources: Techniques, Technologies and Case Studies, Austin, Texas, November 12-13, 2013

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Abstract

This four-month project involved detailed analysis of slabbed core from six basins in Colombia. The majority of the core came from the Llanos, Middle Magdalena, and Catatumbo basins. The overall analytical program consisted of:

Phase 1: Whole Core X-ray CT Imaging, Total Core Scanned:
- 31,058 ft, 139 wells

Phase 2 and 3: Unconventional Rock Quality Workflow MicroCT and 2D SEM analysis was performed on 65 wells (4,357 plugs, 87,000+ 2D SEM images analyzed) top three basins analyzed:
- Catatumbo (1,709 plugs)
- Llanos (842 plugs)
- Middle Magdalena Valley (803 plugs)

3D FIB-SEM analysis was performed on 453 samples. Top 3 basins analyzed •Catatumbo Basin (141 poro-perm samples)
- Middle Magdalena Valley (220 poro-perm analyses)
- Llanos Basin (56 poro-perm samples)

In addition, the core data was integrated with well log data for about 134 wells in order to develop and refine a petrophysical model for unconventional resources. This present

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Results and Methodology from ANH (Colombia) Unconventional Resources Core Project

AAPG GTW Reservoir Quality, Austin, TX

Dr. Joel D Walls, Juliana Anderson, Elizabeth Diaz | Ingrain Inc., Houston

Maria Rosa Ceron | Agencia Nacional de Hidrocarburos, Bogota

12 November, 2013

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Presentation Outline

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- Introduction
- Scope, goals, focus, and timing of project
- Primary focus of this presentation
  - Middle Magdalena Valley Basin
  - Catatumbo Basin
  - Llanos Basin
- Digital Rock Physics Methodology for Unconventional Resources
- Key results and findings
  - Rock Typing and Analog Formations
  - Rock Quality Measures and Comparisons
  - Example Results
- Summary, Future Analysis

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SCOPE, GOAL, FOCUS, AND TIMING

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Scope of Project

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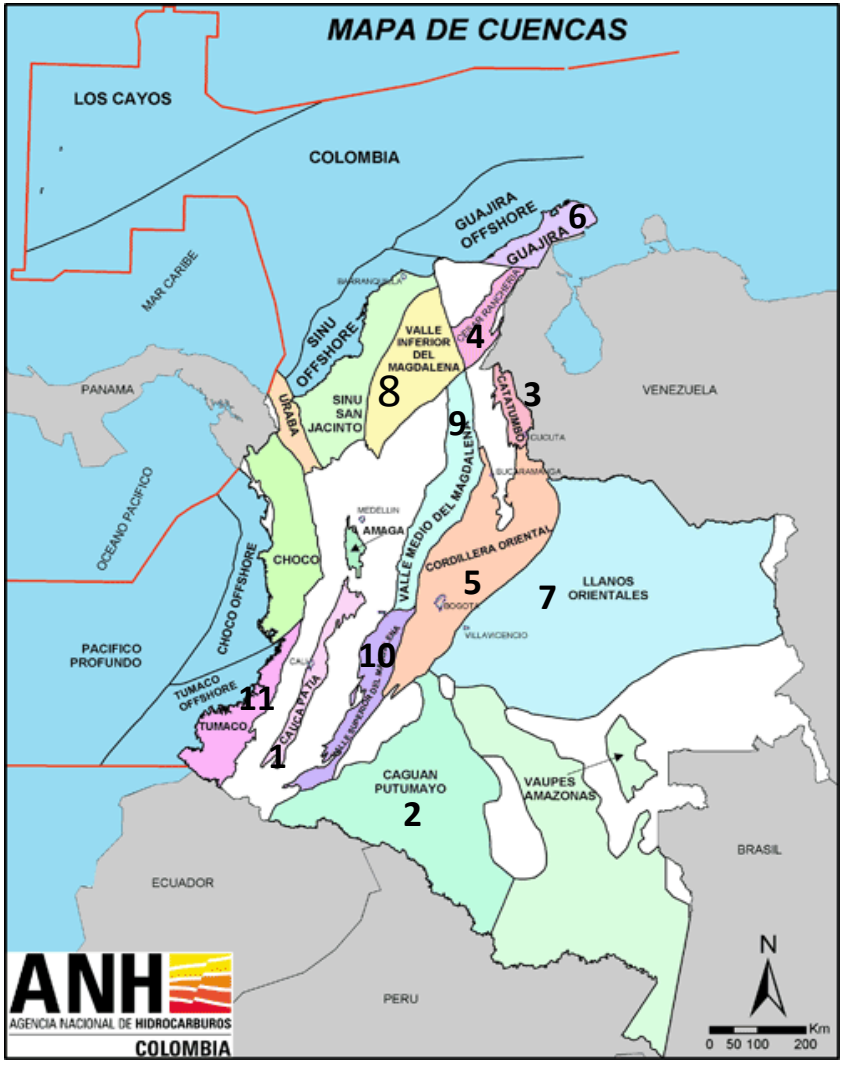

#	Basin	Wells Scanned	Well Logs	Petrophysics Interpretation
1	Cauca-Patia	1	1	0
2	Caguan_Putumayo	4	4	1
3	Catatumbo	24	24	24
4	Cesar Ranchería	2	2	2
5	Cordillera Oriental	3	3	2
6	Guajira	8	7	1
7	Llanos	54	53	37
8	VIM	11	11	1
9	VMM	13	13	3
10	VSM	18	15	2
11	Tumaco CA	1	0	0
	TOTAL	139	134	73

Note: None of the wells in the study were drilled or cored with the intent of unconventional resource analysis.

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Project Overview: Initial Focus in 3 Basins

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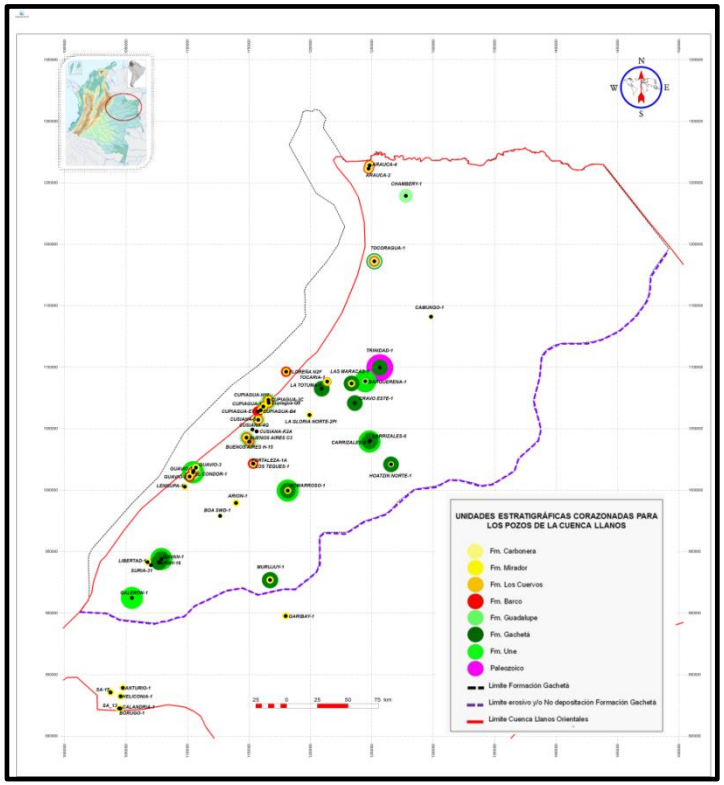
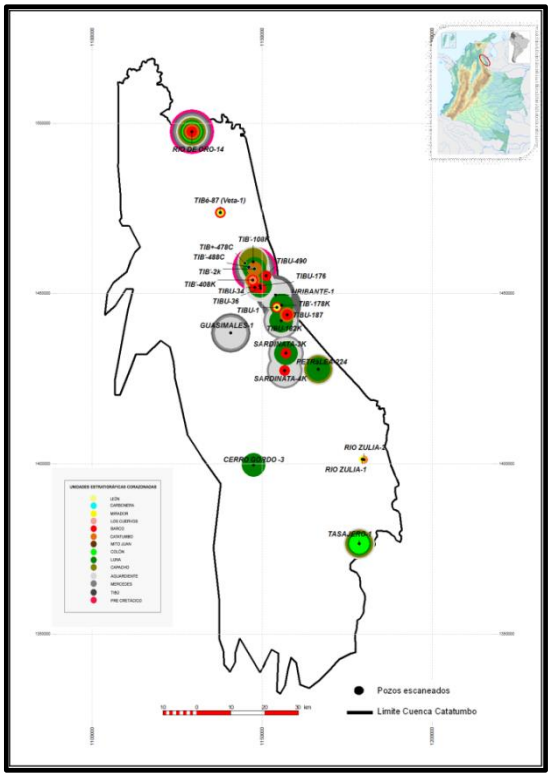
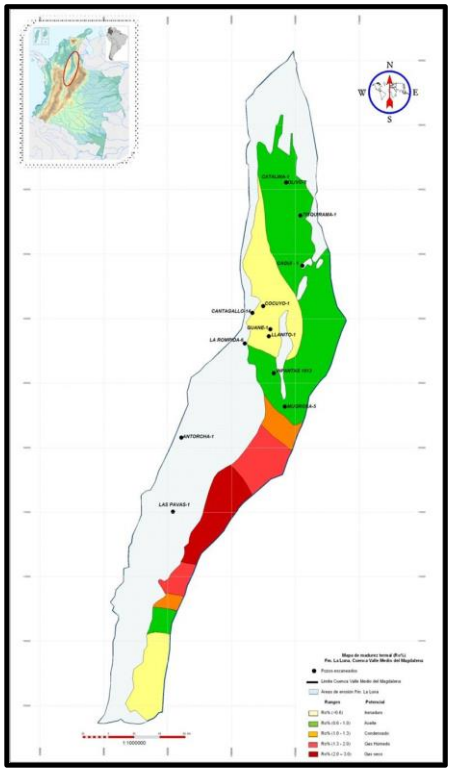


Llanos Basin
54 wells
10019 feet of whole core
842 plug samples



Catatumbo Basin
24 wells
7512 feet of whole core
1709 plug samples



Middle Magdalena Valley Basin
13 wells
2012 feet of core
803 plug samples

Approximately 2/3 of total project involves these three basins.

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Project Overview: Core Data and Analyses

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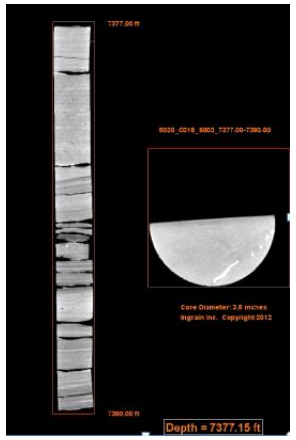
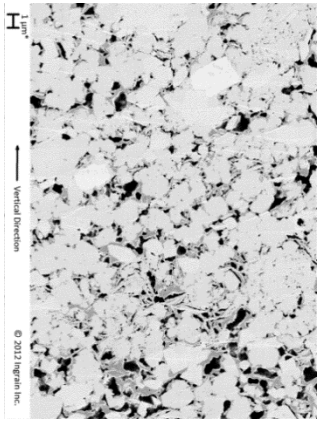
Project Goal: Identify and characterize shale resource potential in key Colombia basins by analyzing archived core and well log data.
Project Start: September 2012
Project Completed: December 2012



Phase 1: Whole Core X-ray CT Imaging

- Total Core Scanned: 31,058 ft
- 139 wells



Phase 2 & 3: Unconventional Rock Quality Workflow

- MicroCT & 2D SEM analysis was performed on 65 wells (4357 plugs, 87000+ 2D SEM images analyzed)
- Top 3 basins analyzed:
  - Catatumbo (1709 plugs)
  - Llanos (842 plugs)
  - Middle Magdalena Valley (803 plugs)
- 3D FIB-SEM analysis was performed on 453 samples.
- Top 3 basins analyzed
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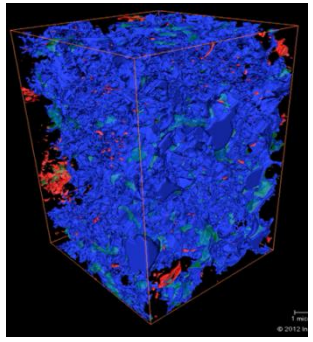

*As part of the unconventional workflow, additional analysis of XRF, EDS mineralogy, and Pore Size Distribution on 2D and 3D volumes was performed.

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Identify and characterize most productive rock in least amount of time.

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Shale imaging from core to pore

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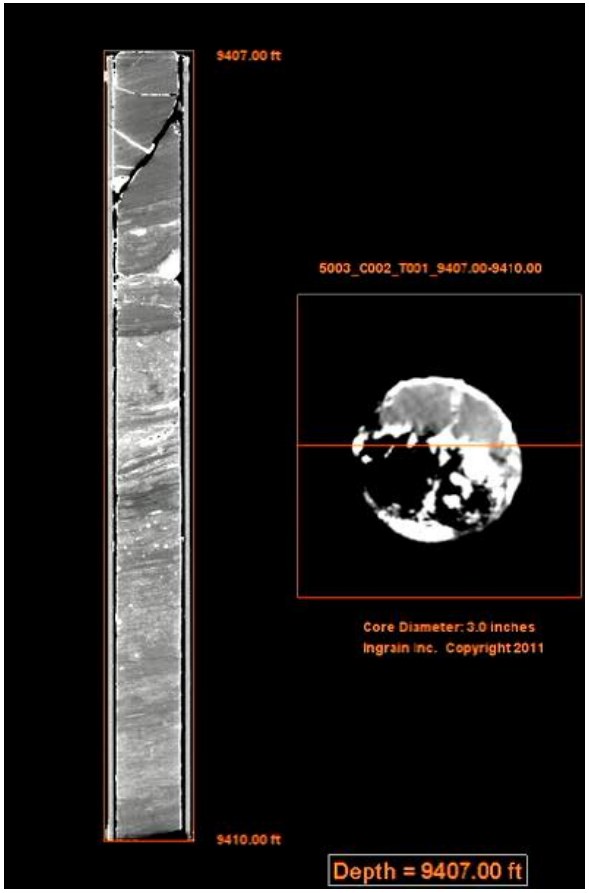

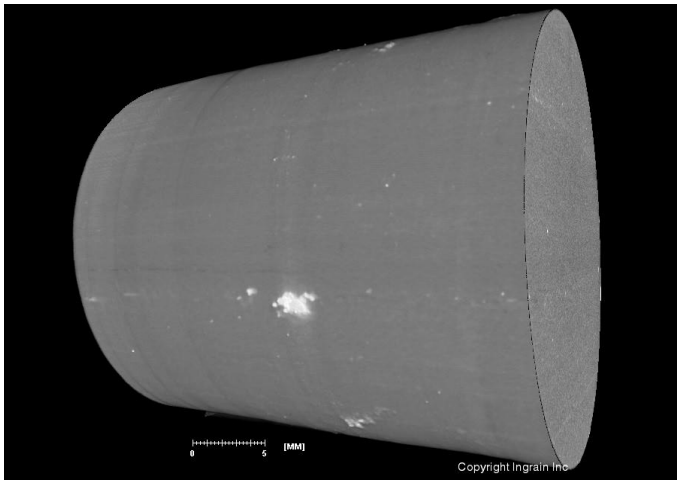

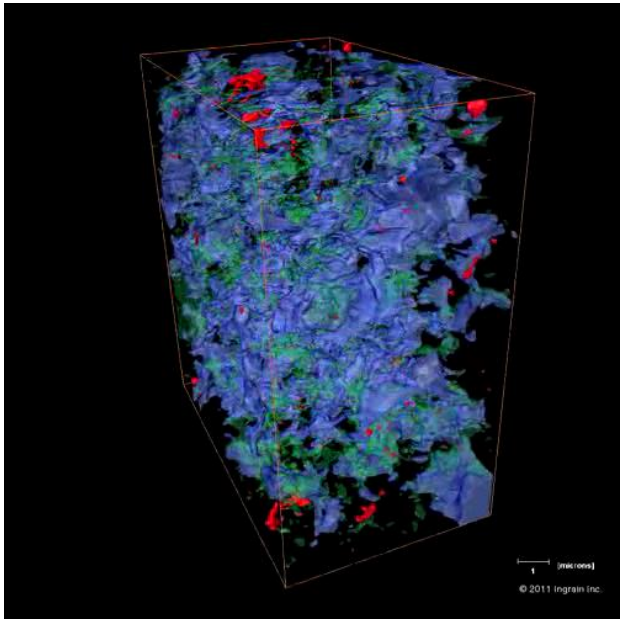

meters

millimeters

microns

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Stage 1, CoreHD®; dual-energy whole core imaging and analysis

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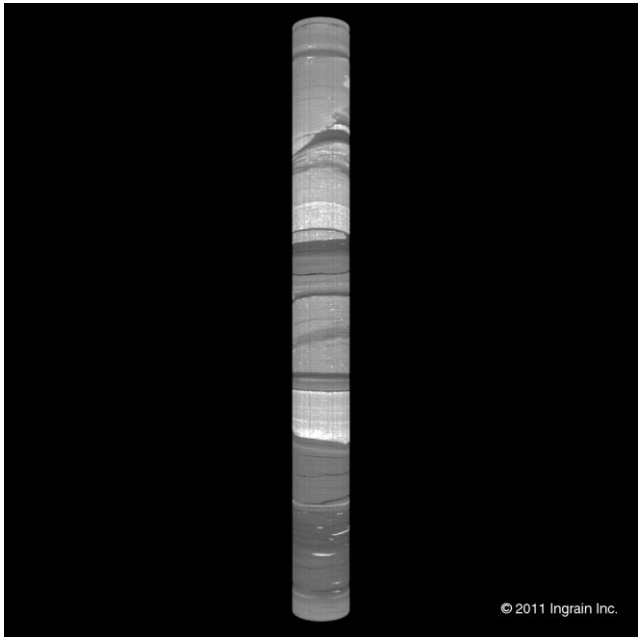
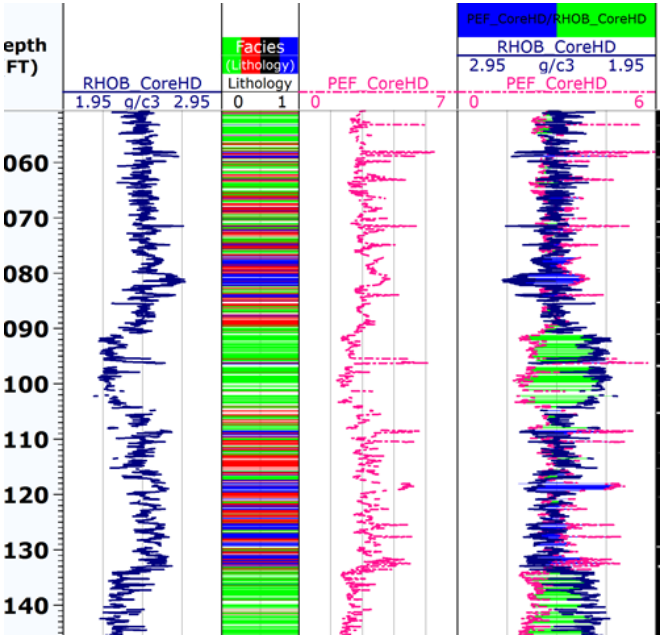
Primary applications of CoreHD

1. Geologic understanding: Analyze fractures, burrows, bedding, fossils, etc.
2. Rapid lithologic characterization and computed rock properties (sweet spots)
3. Well log calibration and corrections, petrophysical modeling
4. Intelligent plug sample depth selection (not regular depth intervals)
5. Archival: Permanent high quality 3D digital image volumes for future work





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Lithology and Reservoir Quality Analysis from RhoB and PEF

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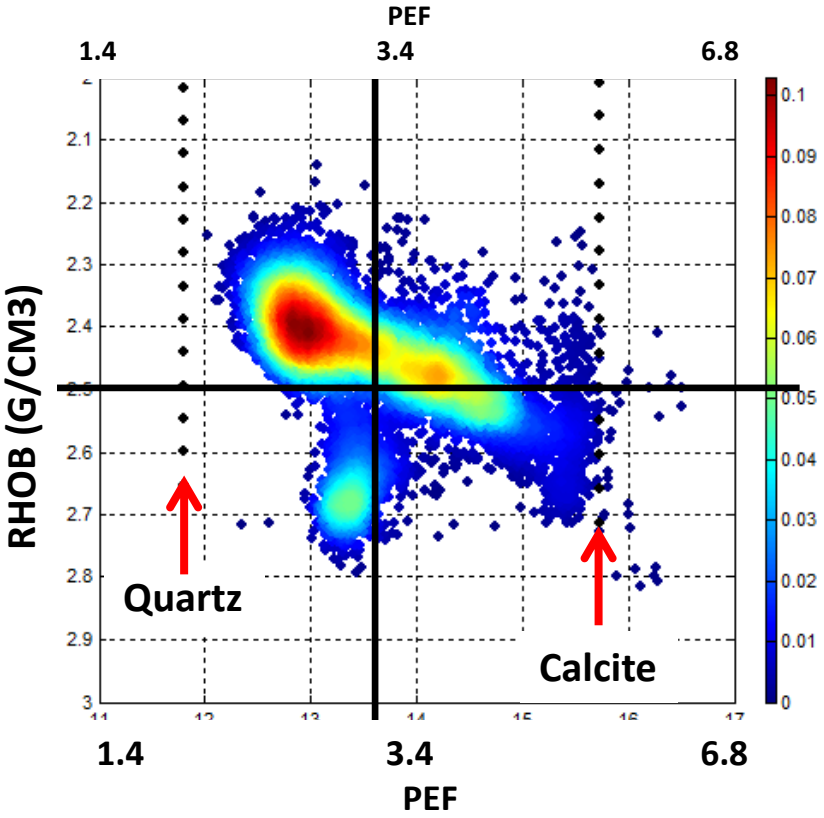
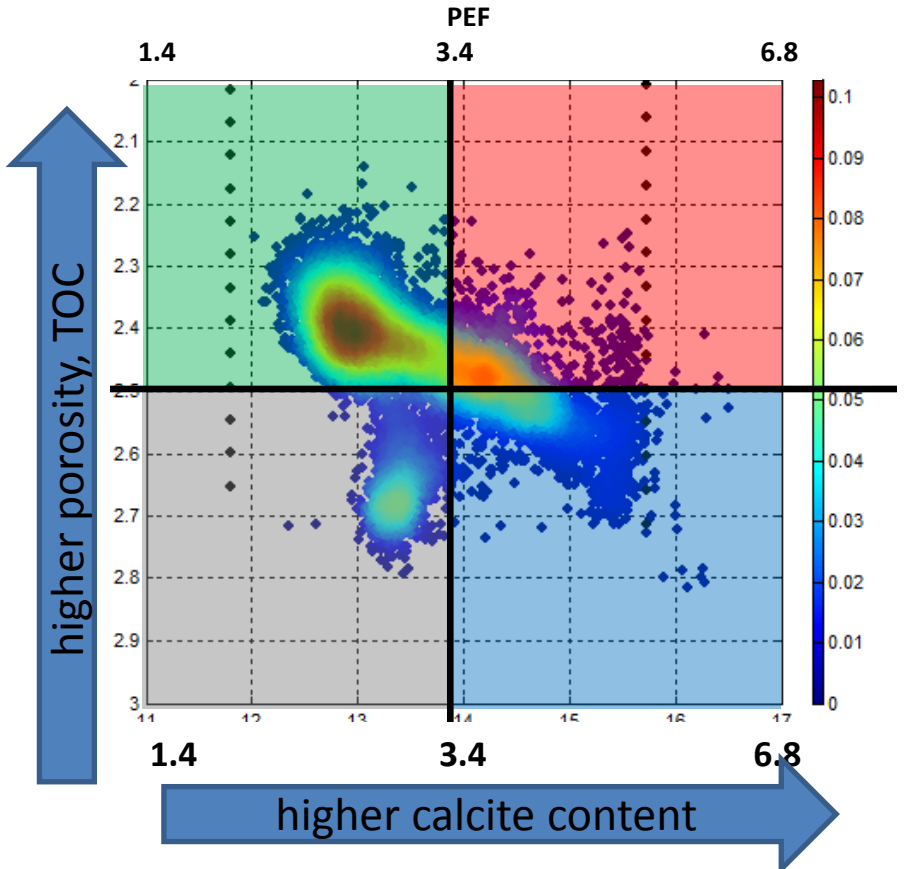


Green = Higher porosity and/or organics

Red = Higher phi or organic, more calcite

Blue = Dense, hard, low TOC, more calcite

Black = Dense, hard, low TOC, more quartz



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Sample Selection for Reservoir Quality Analysis (Stage 2 and 3) using CoreHD Facies

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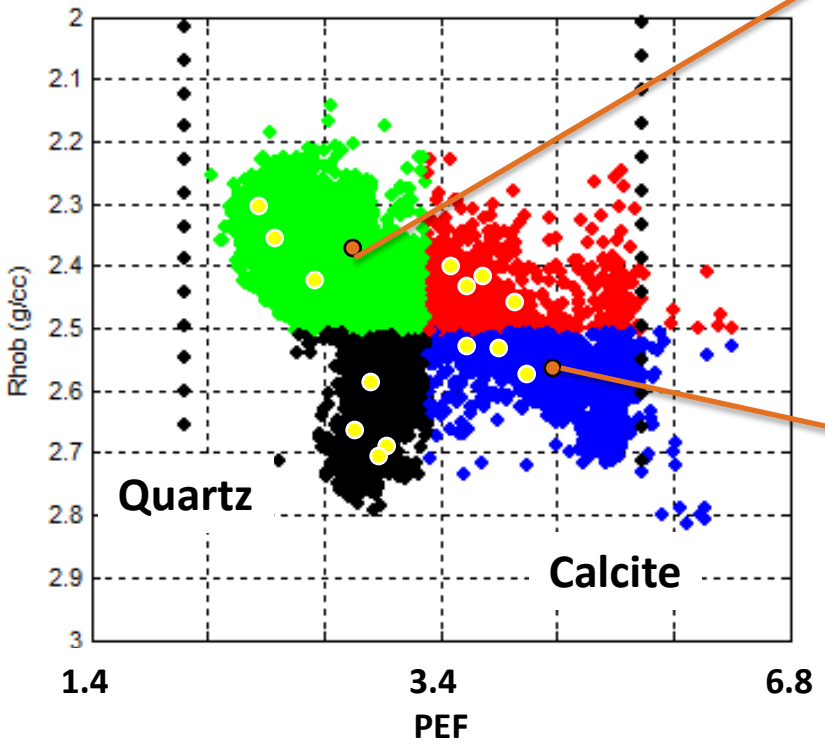

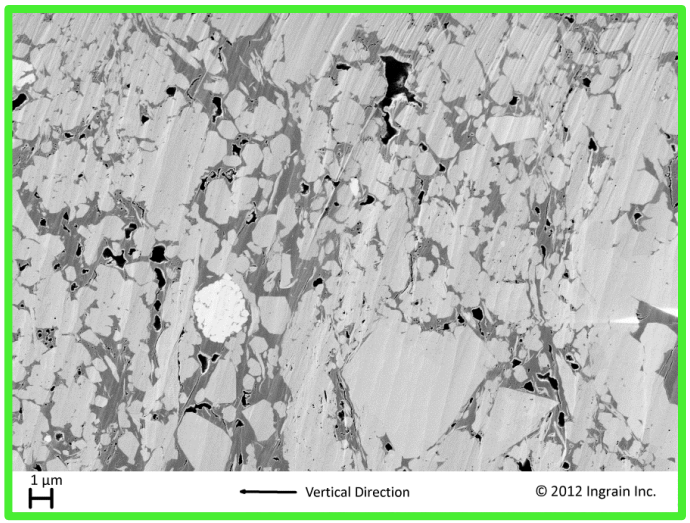

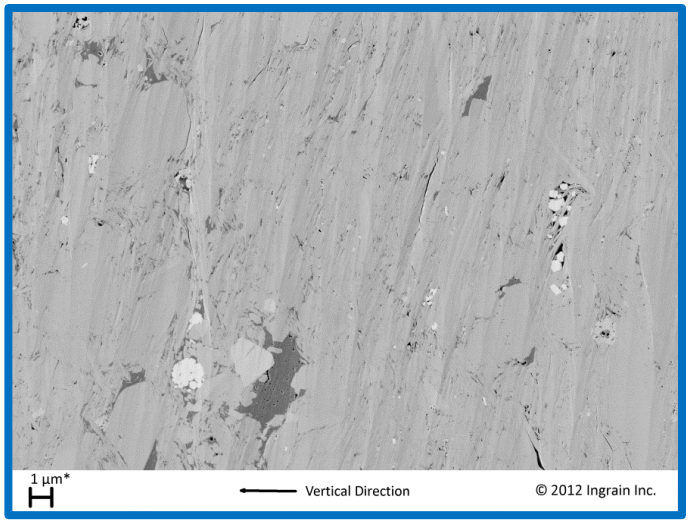

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Stage 3: SCAL - *3D FIB-SEM Showing Pore and Kerogen Systems*

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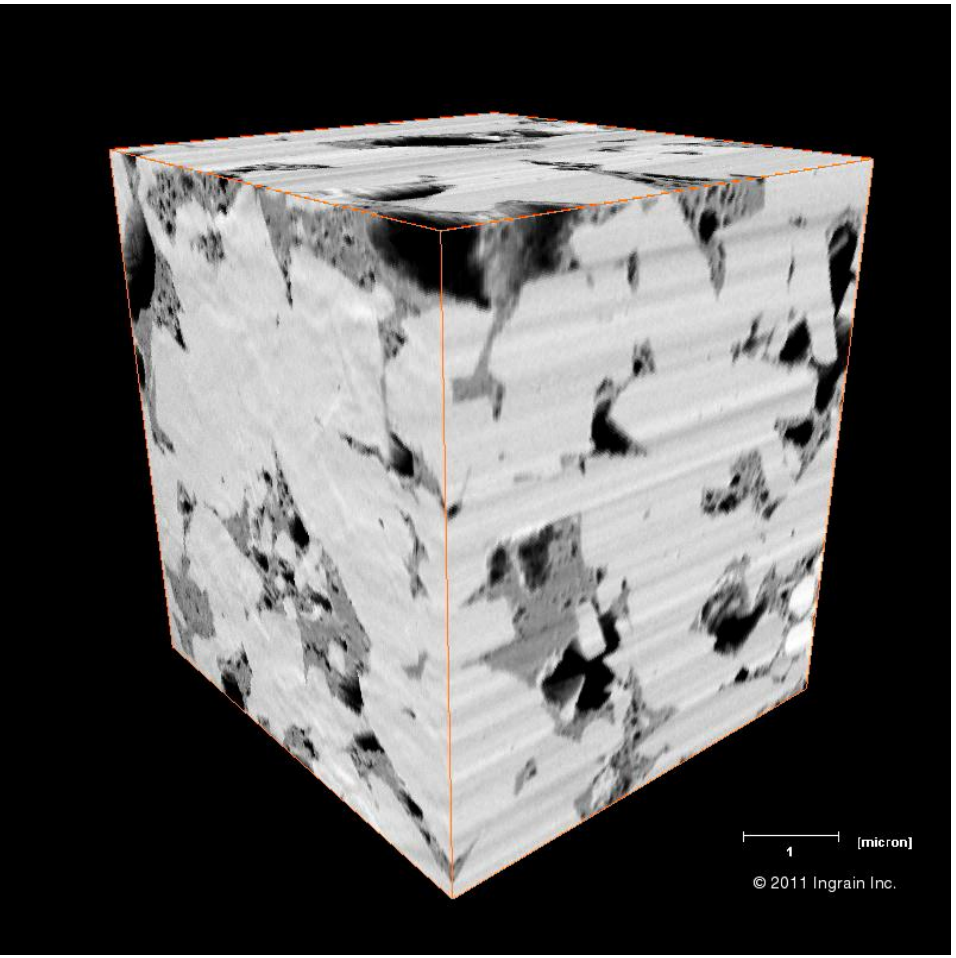
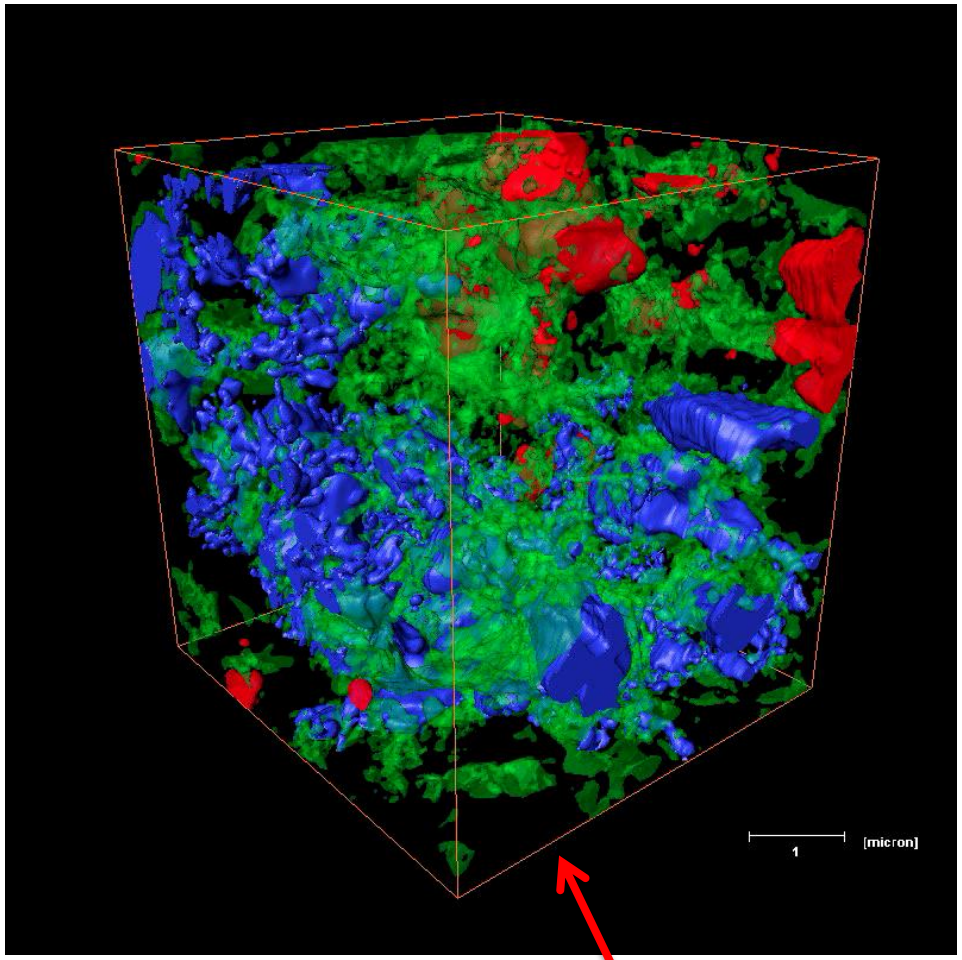
Red: isolated pores
Blue: connected pores
Green: organic material





(total porosity = 12%, Kh = 1034nd, Kv = 30nd)

Perm computed using Lattice Boltzmann method. See Tolke et al, TLE, 2010

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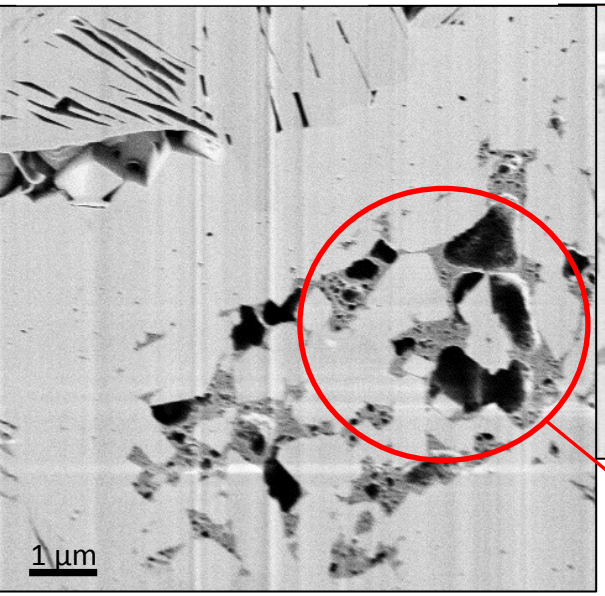
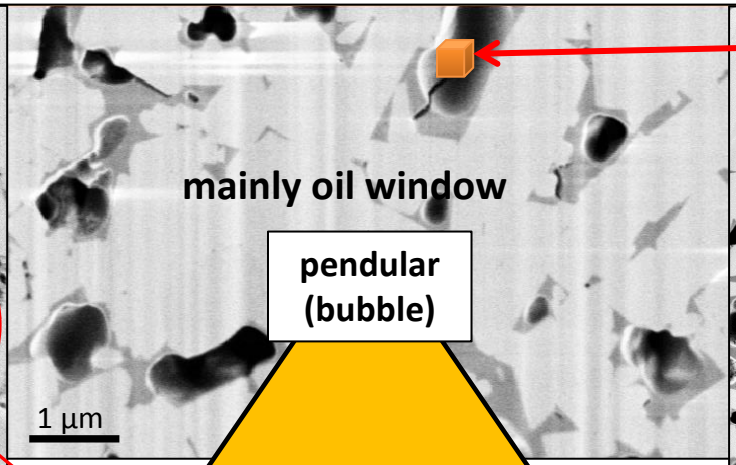
Understanding Organic Porosity Texture

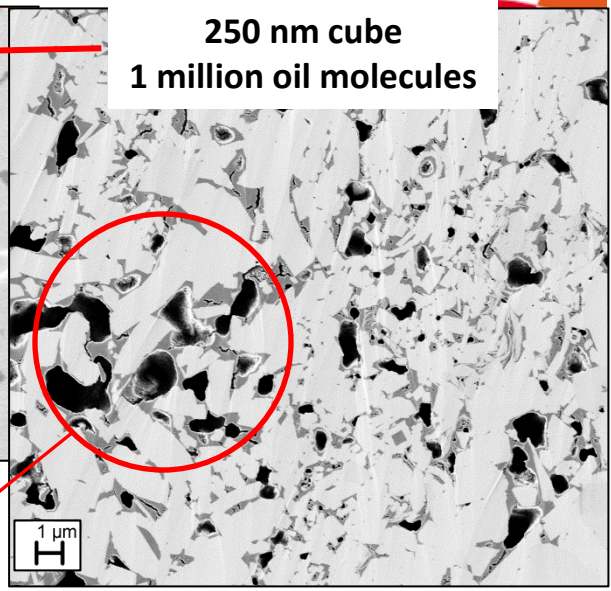
ΔNH

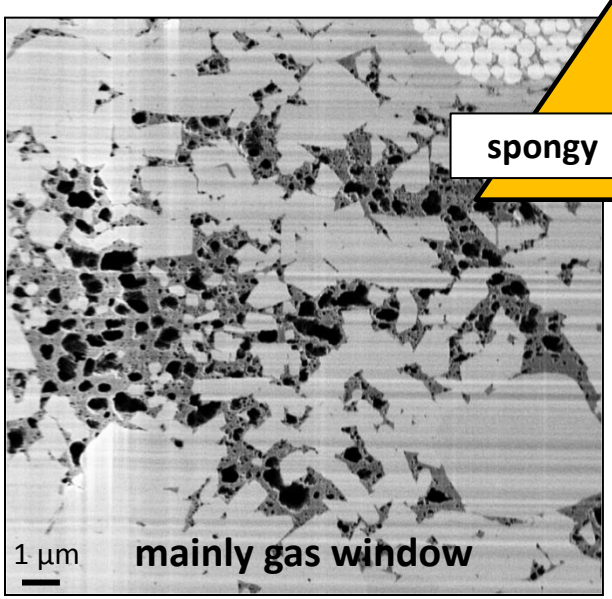




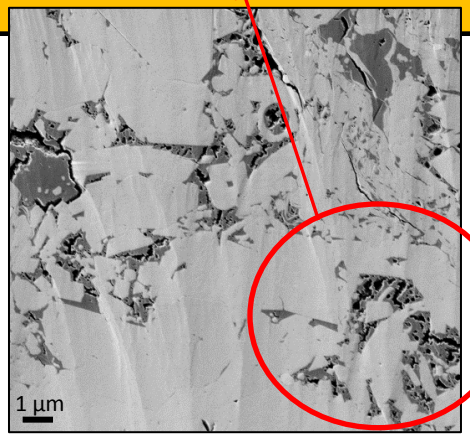
pendular (bubble)

250 nm cube
1 million oil molecules

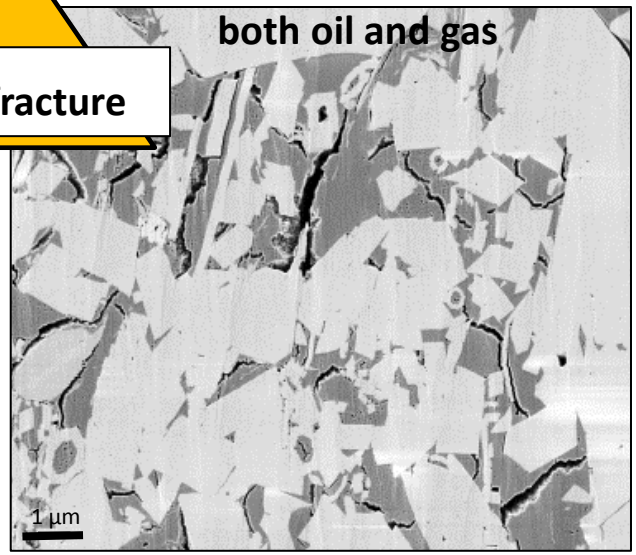




spongy



fracture



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Ingrain Conceptual Rock Model* for Organic Mudstones

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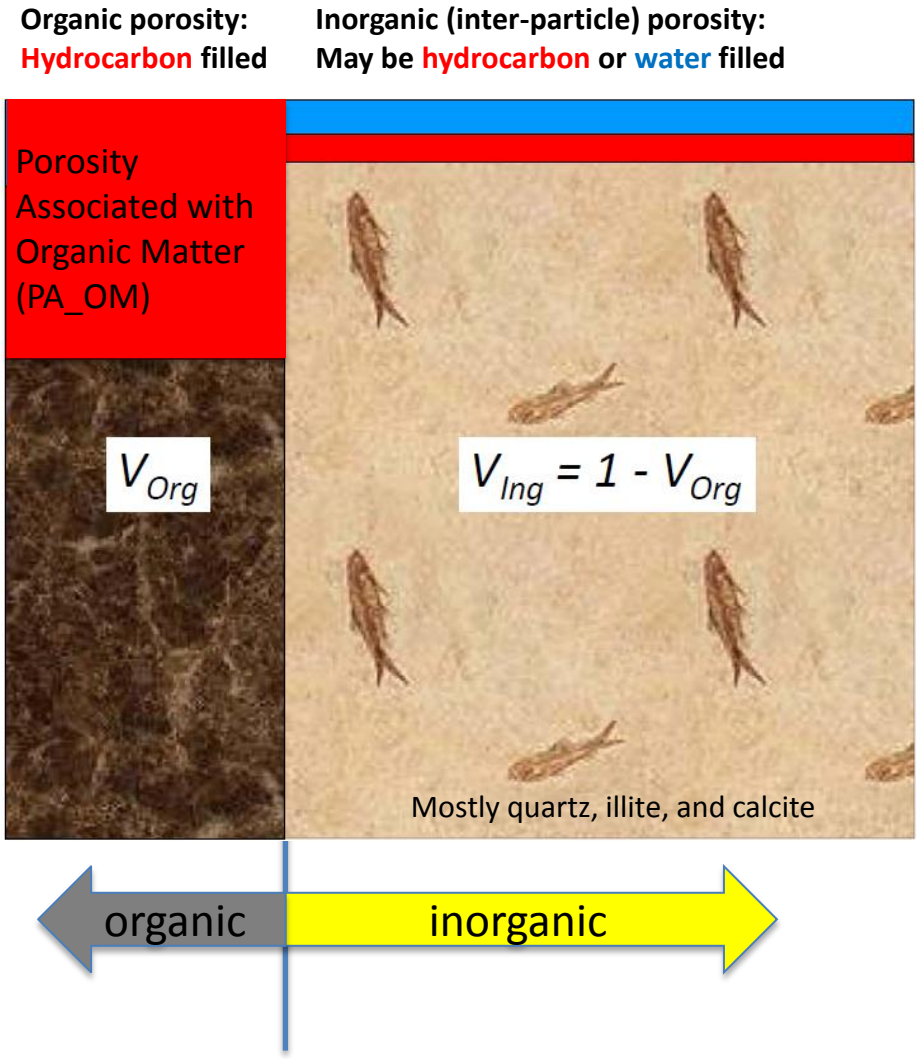
- Organic mudstones appear to be built from a mixture of two components: a more porous organic material, and a lower porosity inorganic mineral phase
- Organic component has porosity from zero to ~50% depending on maturity, type of OM, depth
- Inorganic component has porosity from zero to ~10% depending on mineralogy, depth
- Hypothesis:
  - All organic porosity is hydrocarbon filled
  - Inorganic porosity may contain hydrocarbon and water



*Modified from Peter Day (Marathon Oil), SPWLA Black Shale Conference, 2012

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KEY RESULTS AND FINDINGS

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Examples: Whole Core CT Imaging

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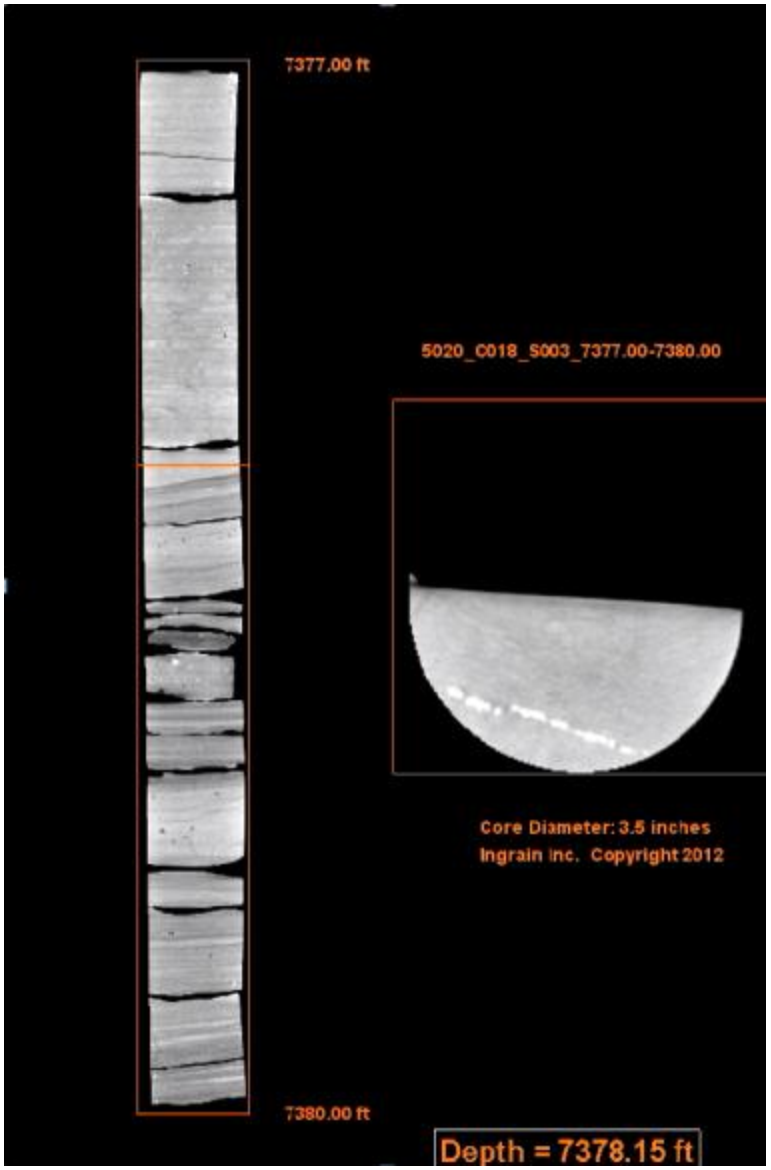

- Half millimeter resolution over entire whole core (500 CT slices/ft)
- Provides the visual information for a detailed geologic description.
- Movies show layering, healed and open fractures, and other geologic features.

Continuous whole core scan from Sardinata Norte - 2 well, Catatumbo Basin

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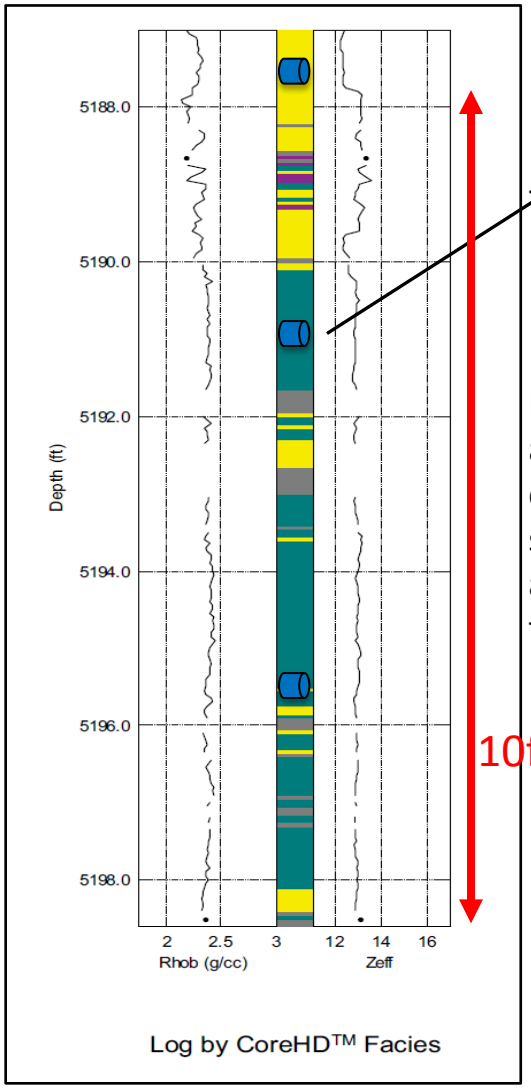
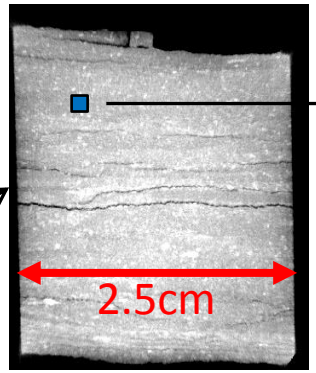
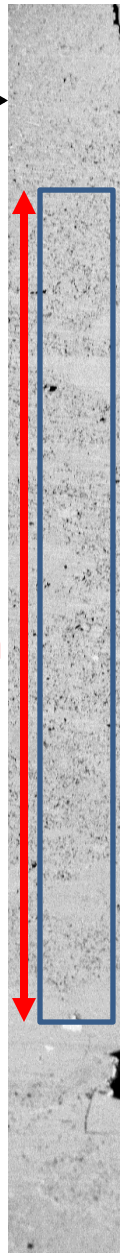
Examples: Sample selection, Micro CT & 2D SEM Imaging

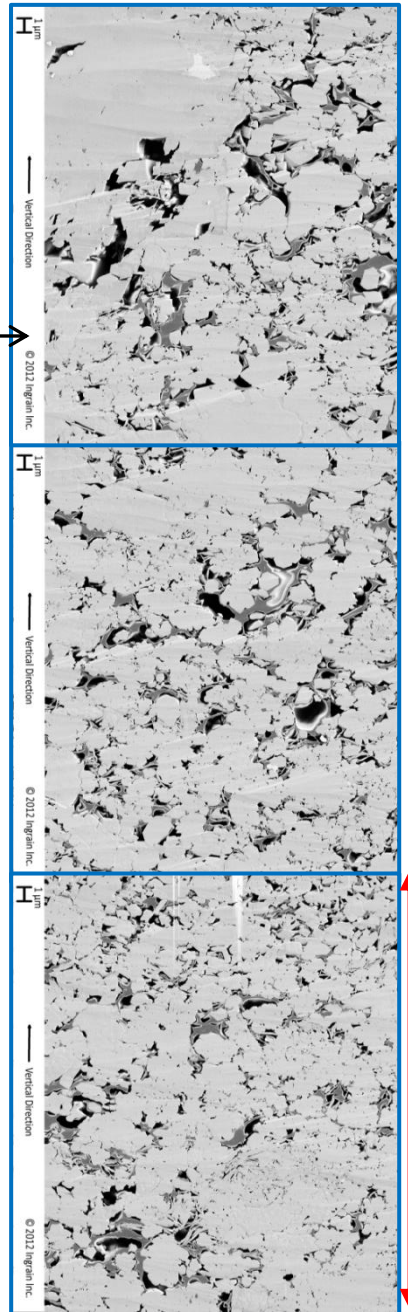


Several 1” plugs are pulled from whole core



Each plug is scanned in an X-ray CT system to characterize the micro-scale heterogeneity. An area (blue) is selected for 2D SEM analysis.





The sample is ion milled (~500 microns) to create a polished surface.

10-15 SE and ESB images are acquired and segmented for porosity, organic matter, and high dense minerals.

Example is from Infantas-1613 well, Sample 315, VMM

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Examples: 3D SEM Imaging

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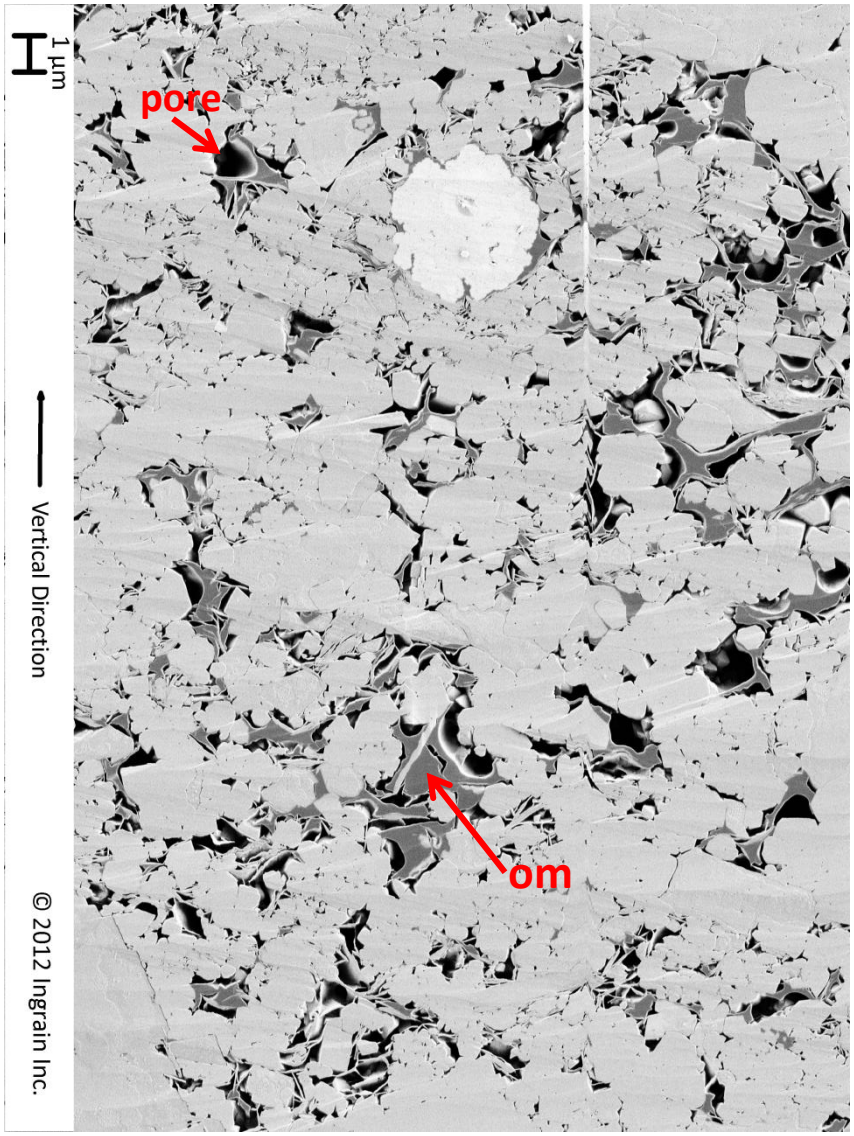
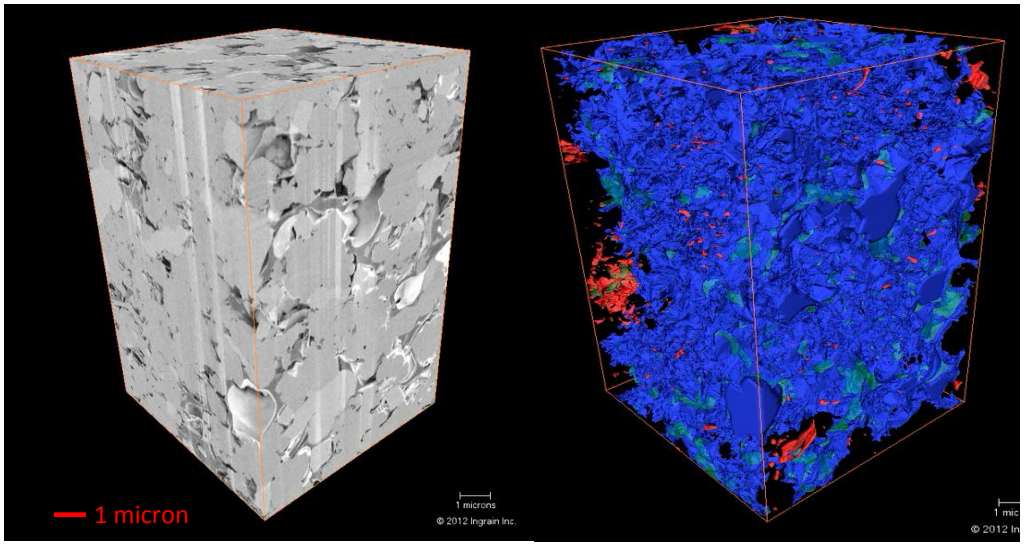


VMM Basin



Surface of 3D FIB-SEM Volume **Pore Volume**

Red: isolated pores Blue: connected pores
Green: organic material

Infantas-1613 Sample 315	Volume %
Total Porosity	10.7
Non-Connected Porosity	0.4
Organic Matter Content	8.6
Porosity Associated with Organic Matter	5.9
Porosity of Organic Material	41
Absolute Permeability (k_Horiz.)	1350 nD

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Rock Quality Analysis – La Luna Fm

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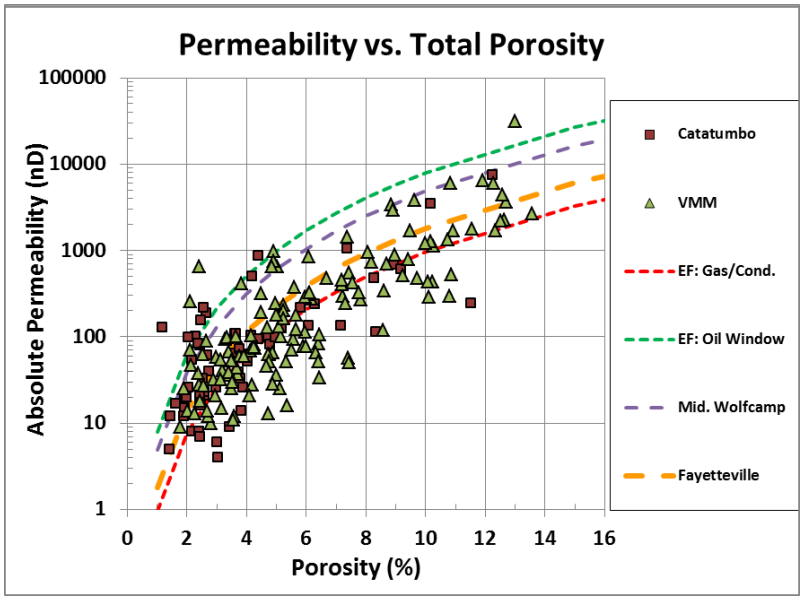

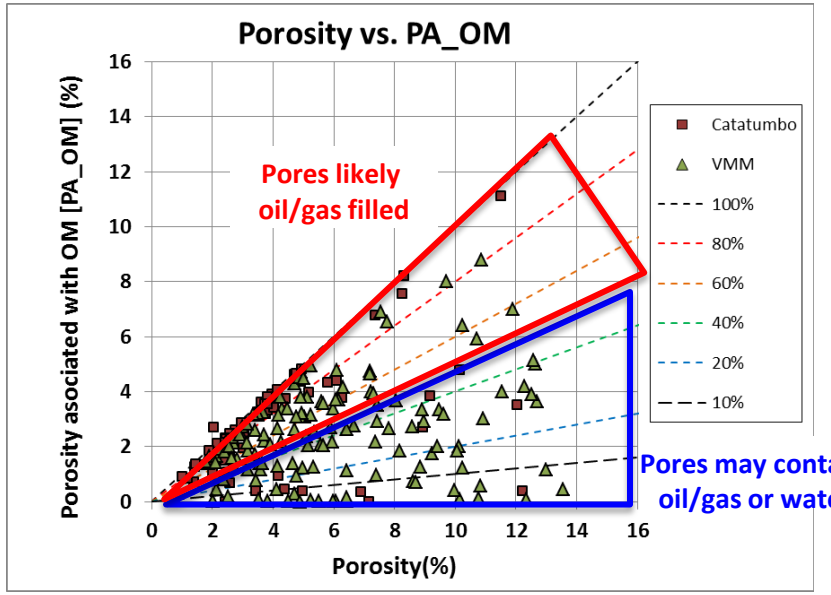

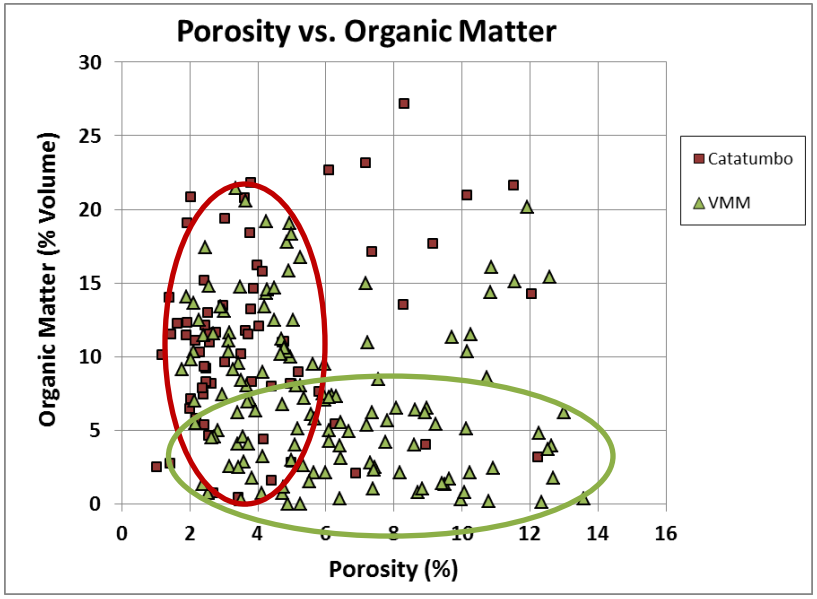

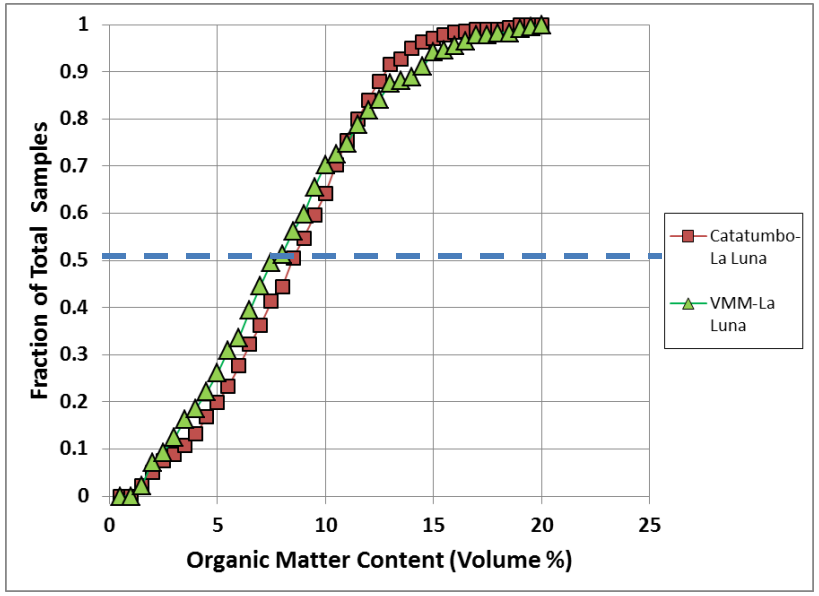

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VMM: Infantas-1613 - Differences in Permeability Related to Pore Types and Sizes

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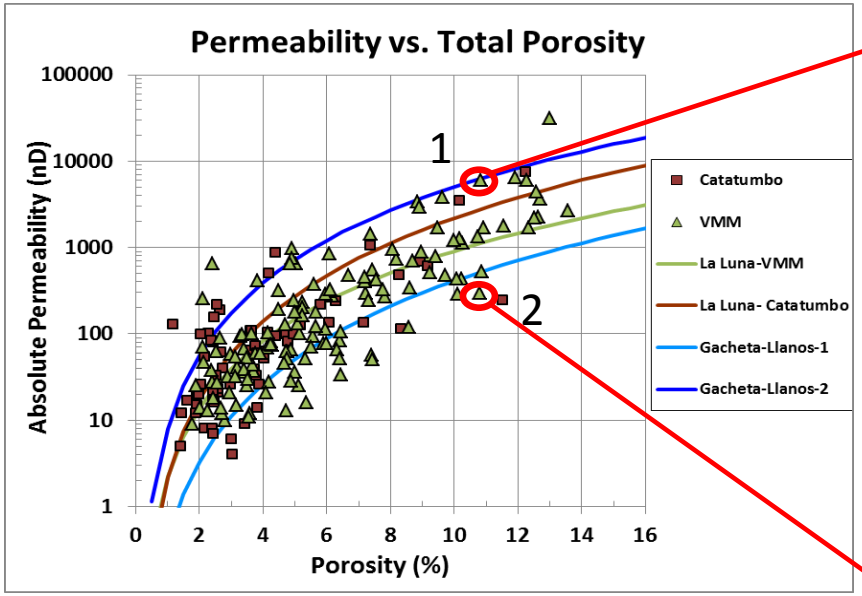
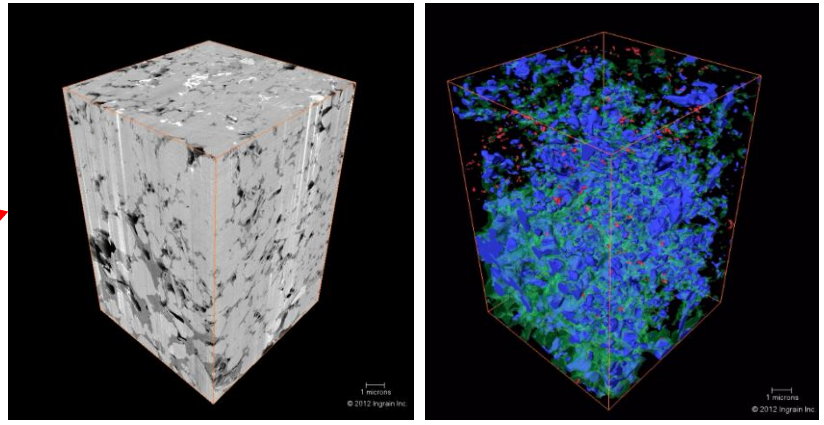


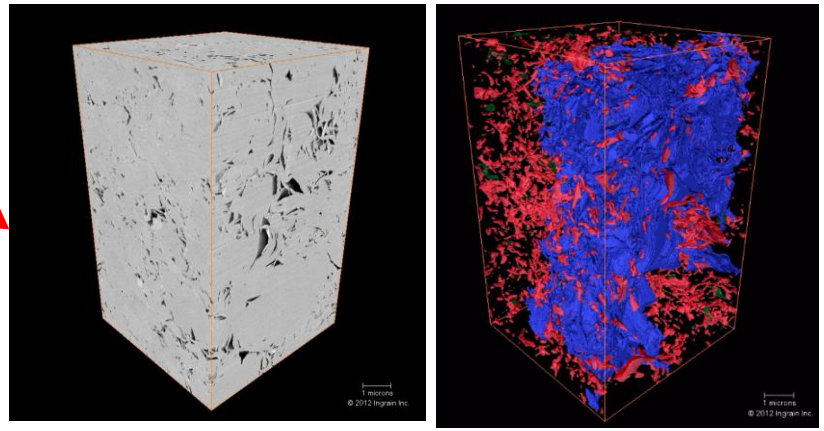
- Sample 1 and 2 have similar porosities, but their permeability values differ.
- Sample 1 contains more organic porosity and is connected through the organic material. This sample has the highest permeability
- Sample 2 contains mostly inter-granular porosity

Infantas-1613 | Salada-La Luna | sample 361 | 6019.7 ft



Porosity=10.84%, OM=14.4%, PA_OM=5.6%,
K_Horiz.=6045nd, Ave pore diameter=180nm

Infantas-1613 | Pujamana-La Luna | Sample 343 | 5595.9 ft



Porosity=10.79%, OM=2.56%, PA_OM=1.1%,
K_Horiz.=297nd, Ave pore diameter = 45nm

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Rock Quality Analysis – 3 Basins- 2 Formations (Comparable to N. America)

Averages	La Luna VMM	La Luna Fm Catatumbo	Llanos Gacheta	Middle Wolfcamp	Lower Eagle Ford	Fayette-ville
Depth Range (ft) Core Samples	2742- 12405	4057- 8310	5928- 10876	5600- 11000	3800- 13000	2100-7700
Porosity (%)	6.3	4.8	5.1	6.4	7.3	4.3
Organic porosity (% of Total Porosity)	47%	71%	51%	60%	67%	80%
Solid Organic Material (vol %)	7.7	8.1	4.7	7.0	5.2	9.6
Porosity of Organic Material	29%	20%	27%	22%	39%	23%
Permeability (K_horizontal)	920	733	982	200	730	120
Maturity (Ro), Kerogen Type	0.6 – 1.0 (Increasing to south & east) Type II	0.6 – 2.0 (Increasing to south) Type II	0.5 – 0.8 (Increasing to west) Type III	0.7-1.0	0.8 to 1.6	1.2-1.5
Likely Hydrocarbon Type	Mostly Oil	Mostly condensate	Conden- sate to gas	Oil to conden- sate	Oil to dry gas	Dry gas

Caution: Averages can be deceiving! There is large variability depending on facies, depth, organic pore type, and other factors.

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Summary

ANH

- Rock quality of La Luna (VMM and Catatumbo) similar or better than many North America shale plays. Gacheta formation in Llanos may be prospective but data is limited.
- Rock property ranges;
  - Catatumbo – Poro; 3-12%; TOC (vol%) 5-27; Permeability 10 – 1000nd
  - VMM - Poro; 2-13%; TOC (vol%) 0-20; Permeability 10 – 10000nd
  - Llanos - Poro; 2-12%; TOC (vol%) 0-5; Permeability 10 – 1000nd (2 wells only)
- Rock quality compared to analogs.
  - La Luna, Catatumbo -----TOC higher, poro slightly lower, perm higher than Wolfcamp or LEF
  - La Luna, VMM----------Porosity similar and permeability higher than middle Wolfcamp
  - Gacheta, Llanos----------Porosity and permeability similar to Fayetteville
- Large variability by depth and well location.
- Tier 1 Unconventional Prospect: LaLuna; Catatumbo and VMM
- Tier 2 Unconventional Prospect: Lower Gacheta; Llanos