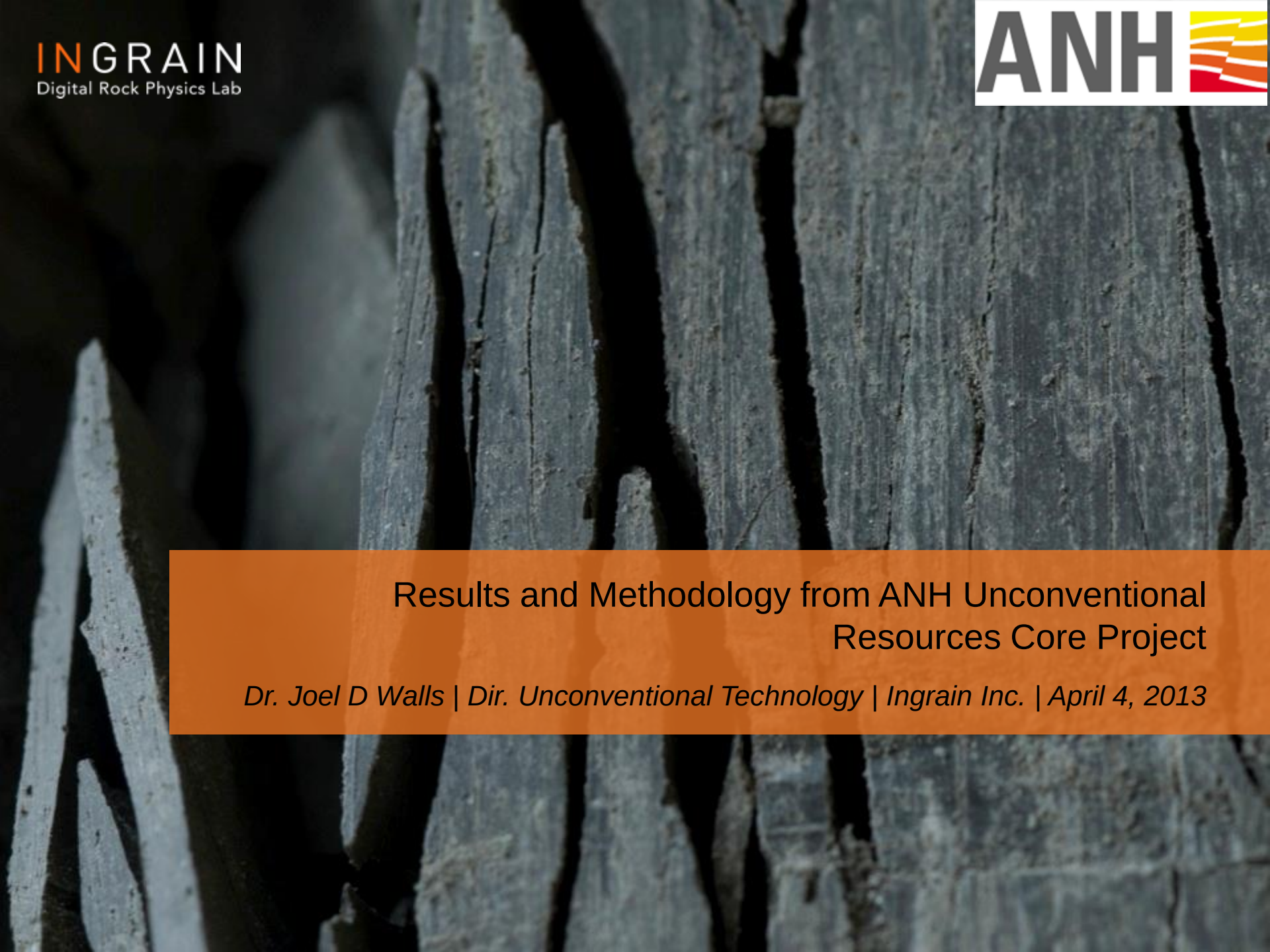

Results and Methodology from ANH Unconventional Resources Core Project

Dr. Joel D Walls | Dir. Unconventional Technology | Ingrain Inc. | April 4, 2013

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Presentation Outline

ANH

- 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, Recommendations

Rock Quality Analysis – 3 Basins- 2 Formations

Averages	La Luna VMM	La Luna Fm Catatumbo	Llanos Gacheta	Middle Wolfcamp	Lower Eagle Ford	Fayetteville
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 in 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.

SCOPE, GOAL, FOCUS, AND TIMING

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Scope of Project

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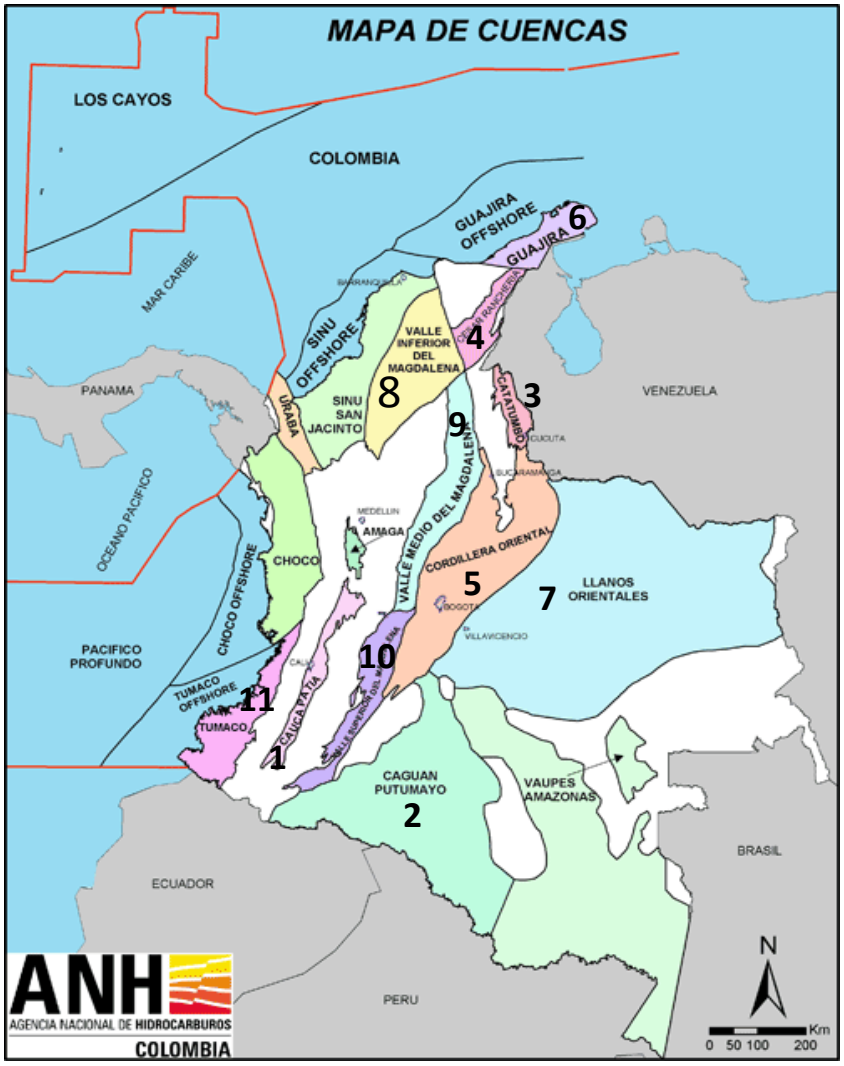

#	Basin	Wells Scanned	Well Logs	Petrophysics Interpretation
1	Cauca-Patia	1	1	0
2	Caguan_Putumayo	4	4	1
3	Catatumbo	24	24	24
4	Cesar Ranchería	2	2	2
5	Cordillera Oriental	3	3	2
6	Guajira	8	7	1
7	Llanos	54	53	37
8	VIM	11	11	1
9	VMM	13	13	3
10	VSM	18	15	2
11	Tumaco CA	1	0	0
	TOTAL	139	134	73

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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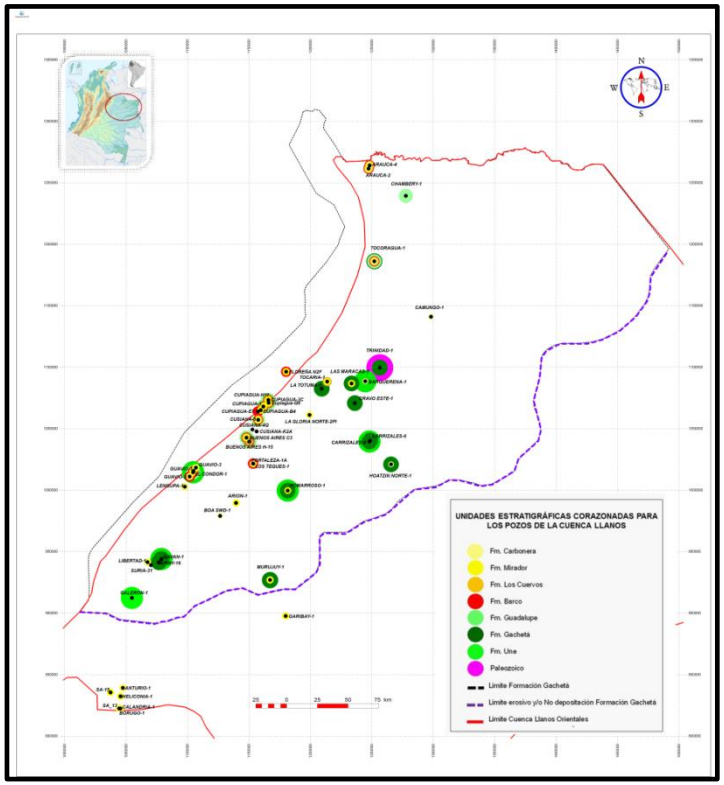
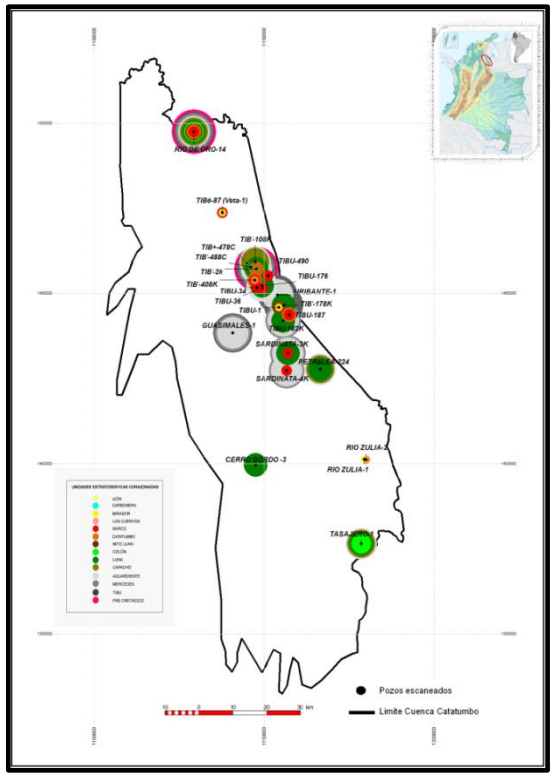
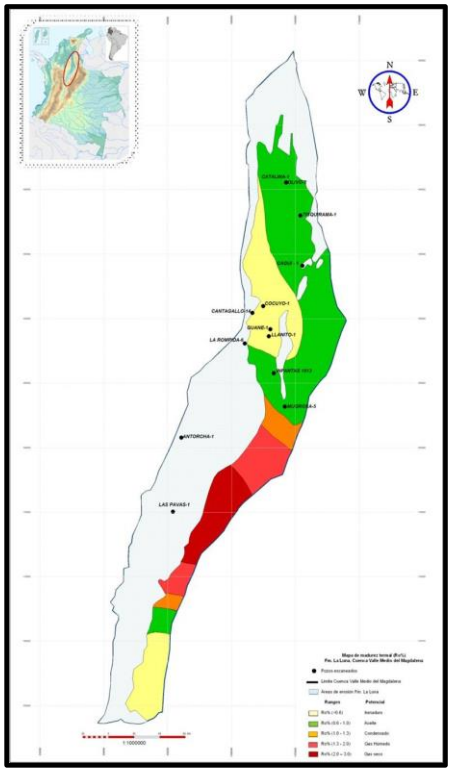


Llanos Basin
54 wells
10019 feet of whole core
842 plug samples



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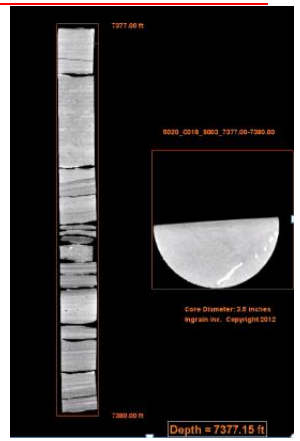
Project Goal: Identify and characterize shale resource potential in key Colombia basins by analyzing archived core and well log data.
Project Start: September 2012
Project Completed: December 2012

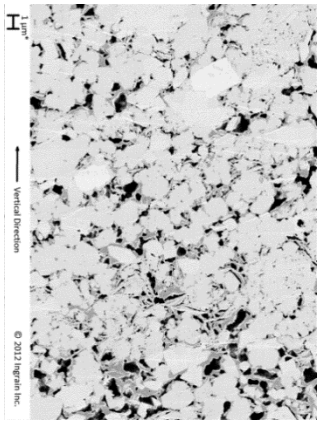


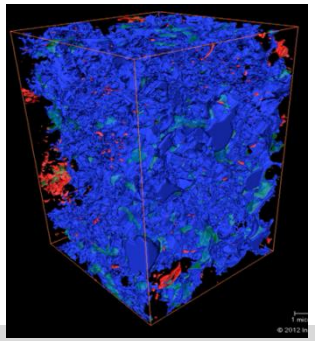
Phase 1: Whole Core X-ray CT Imaging

- 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
  - Catatumbo Basin (141 poro-perm samples)
  - Middle Magdalena Valley (220 poro-perm samples)
  - Llanos Basin (56 poro-perm samples)





*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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Basin Studies for Catatumbo, Middle Magdalena Valley, and Llanos Basins

Each study includes:

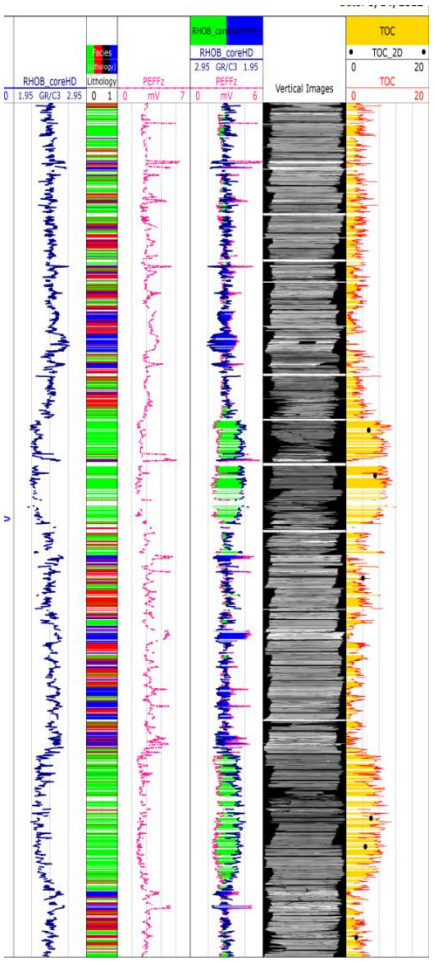
- Geological Integration
- Tectonic and Sedimentary Evolution of the Basin
- Lithostratigraphy
- Structural Evaluation
- Stratigraphy Evaluation
- Stratigraphy Integration with Ingrain Data
- Petrophysical Evaluation
- Petroleum Systems
- Geological Integration with Ingrain results

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

DIGITAL ROCK PHYSICS METHODOLOGY FOR UNCONVENTIONAL RESOURCES

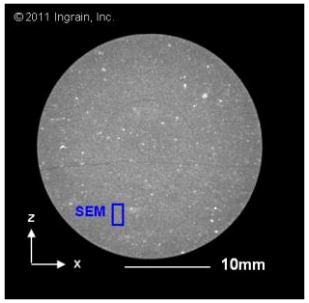
Shale Digital Rock Physics Workflow

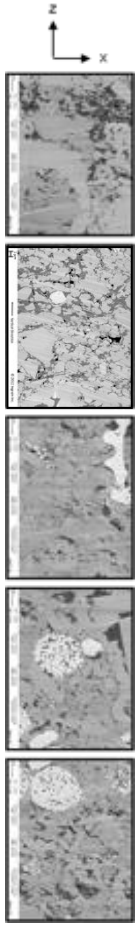
Stage 1: CoreHD™; whole core bulk density, PEF

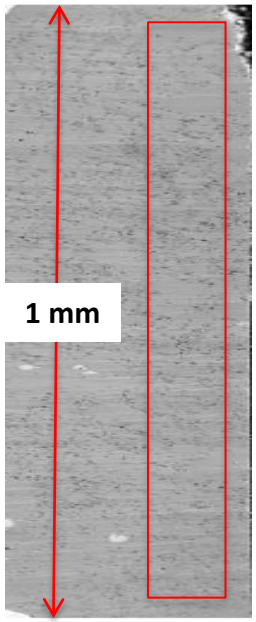


Dual energy X-ray CT

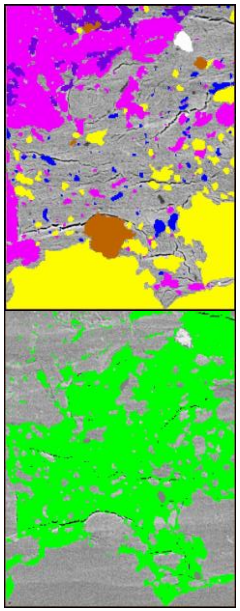
Stage 2: Plugs, chunks, or chips; Porosity, TOC, Mineralogy





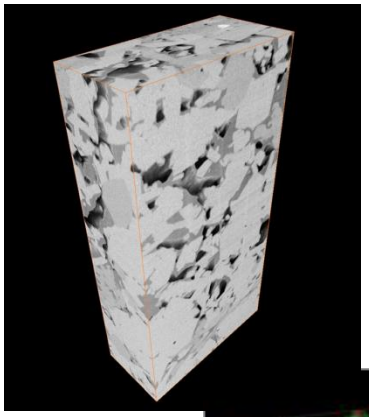


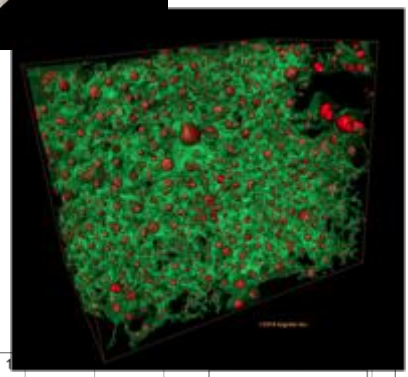
Phase	Area (%)
Clay	49.1
Organics	0.3
Quartz	21.9
K-Feldspar	2.4
Plagioclase	20.2
Pyrite	0.4
Calcite	1. 8
Dolomite	3.5

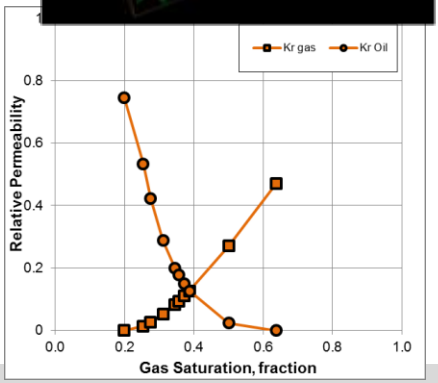


Micro-CT, SEM, and EDS

Stage 3: Directional Permeability and SCAL







FIB-SEM

Shale Digital Rock Physics Workflow (Cuttings)

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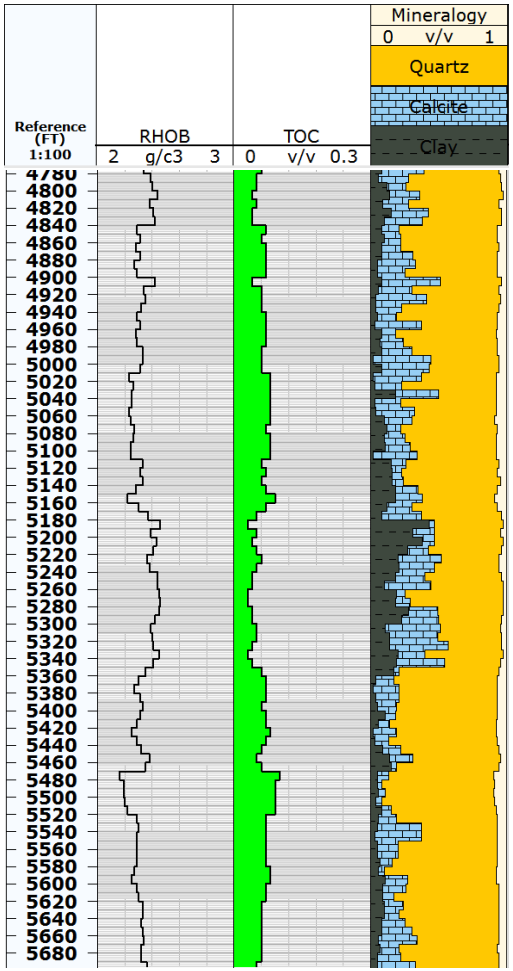
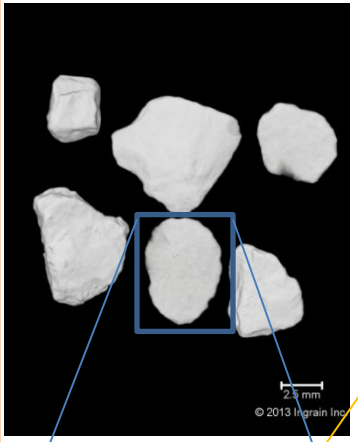
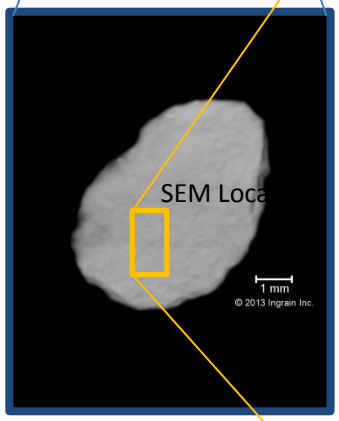
Stage 1: ReconHD™

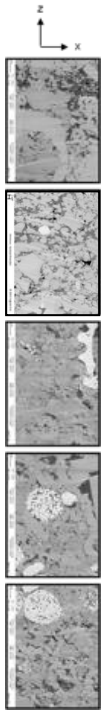
Sieved bag samples
(10 to 20 ft intervals)

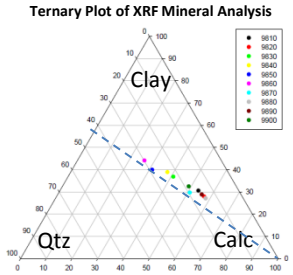


Stage 2: Cuttings Analysis for Mineralogy, TOC, Porosity

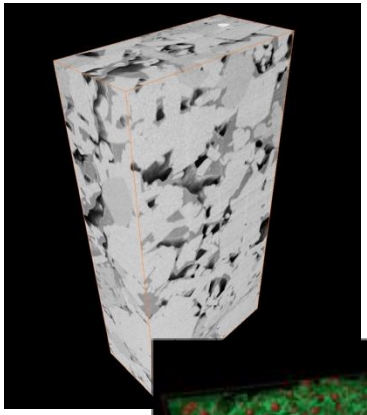


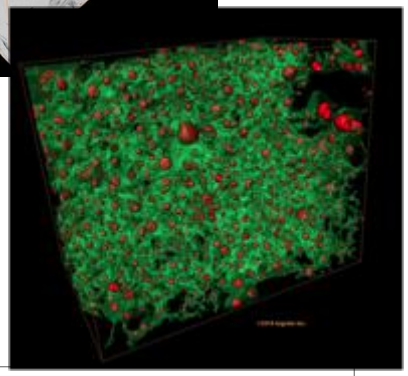


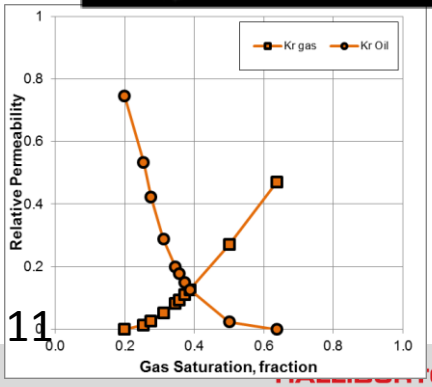




Stage 3: Perm and SCAL







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

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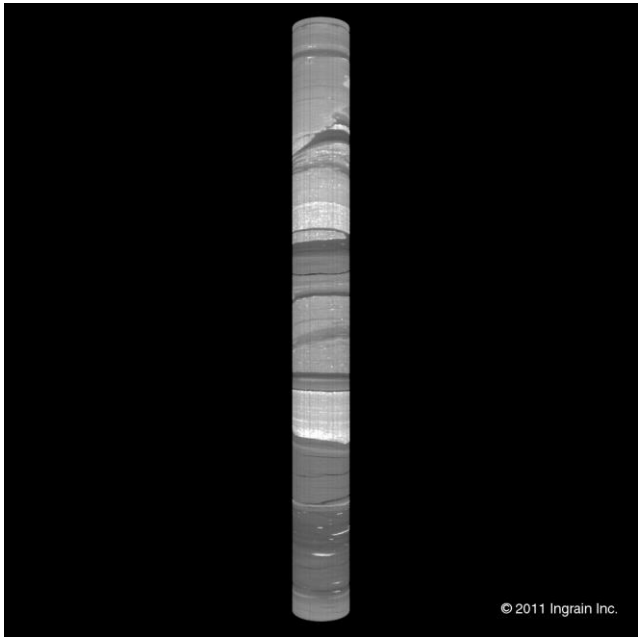
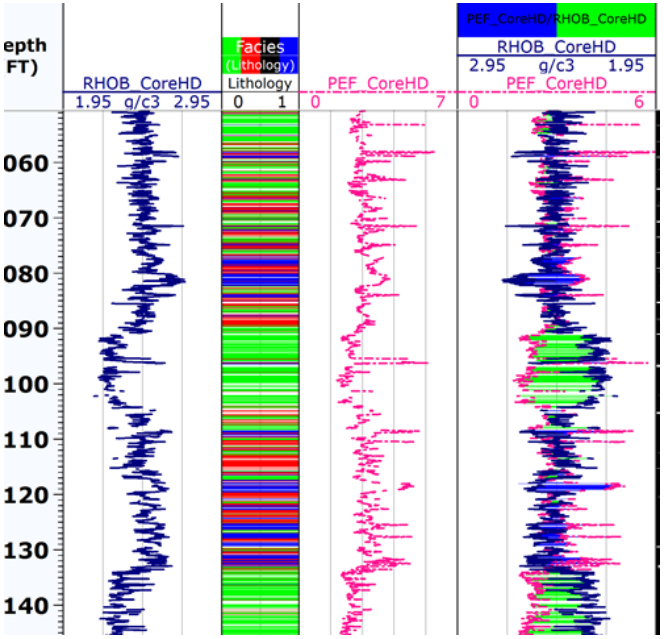
Primary applications of CoreHD™

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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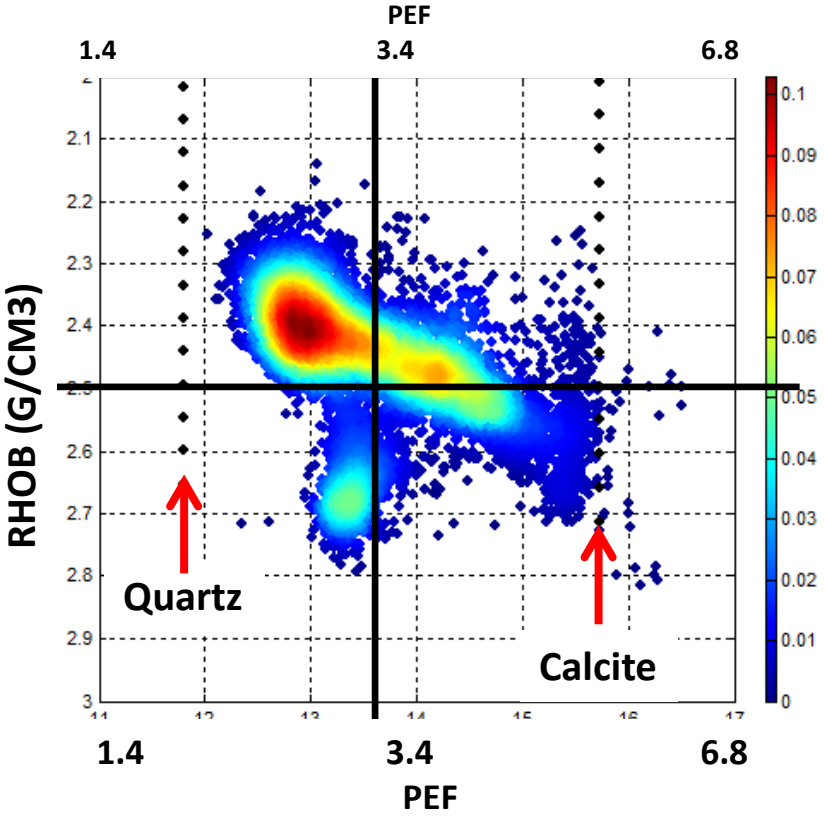
Lithology and Reservoir Quality Analysis from RhoB and PEF

ANH

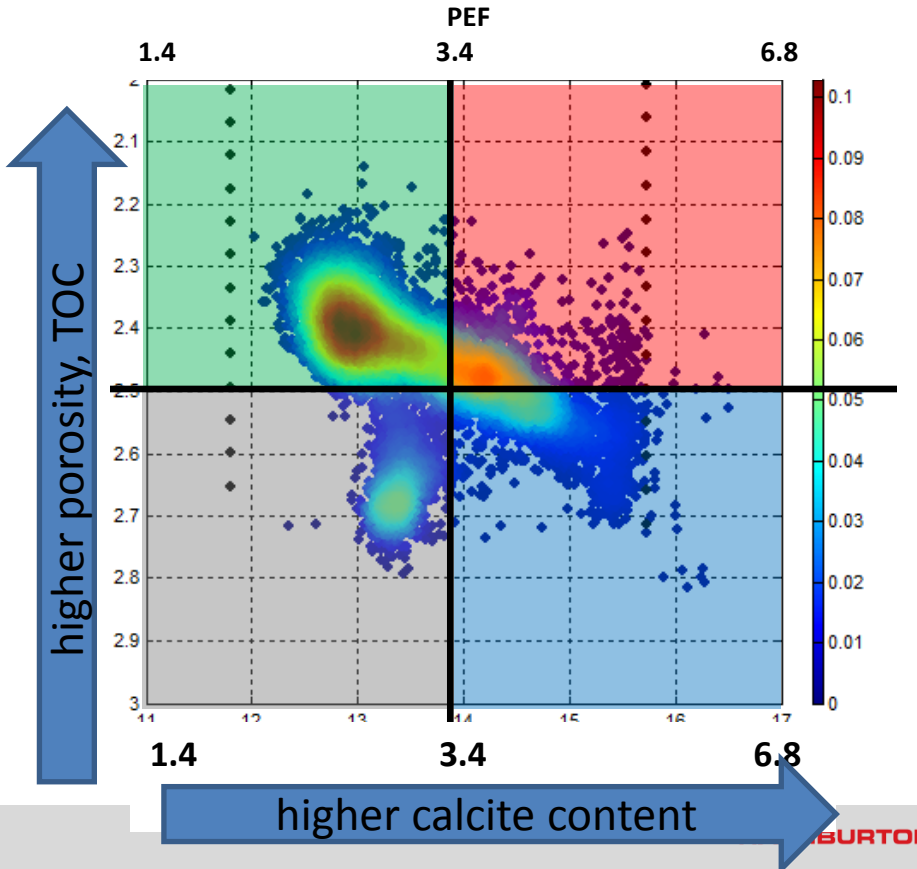


Green = Higher porosity and/or organics

Red = Higher phi or organic, more calcite

Blue = Dense, hard, low TOC, more calcite

Black = Dense, hard, low TOC, more quartz



BURTON

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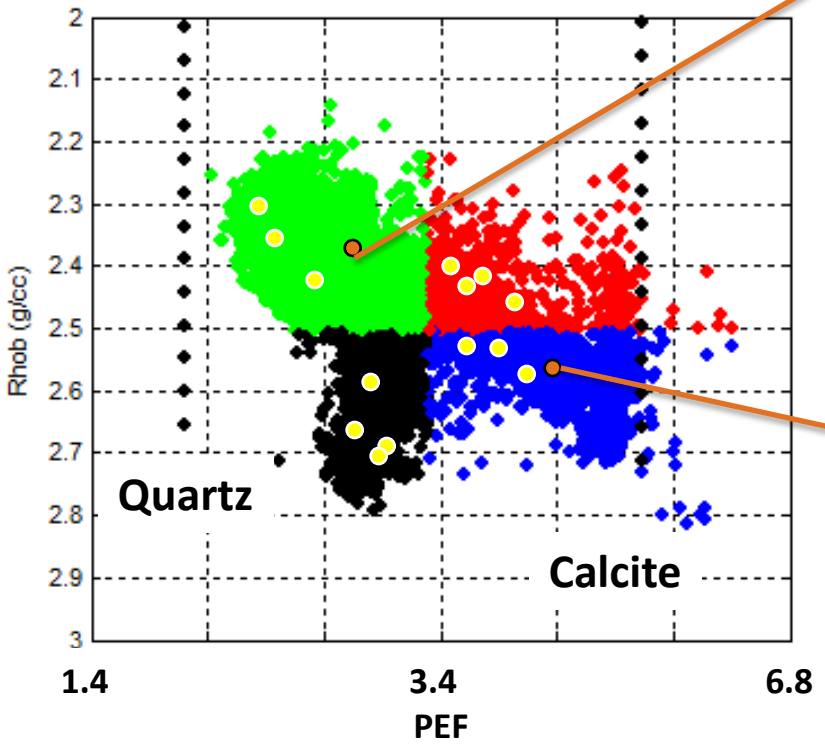
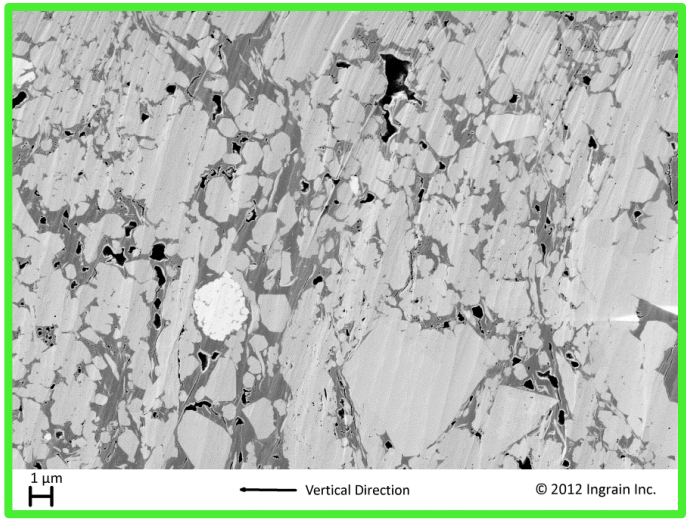
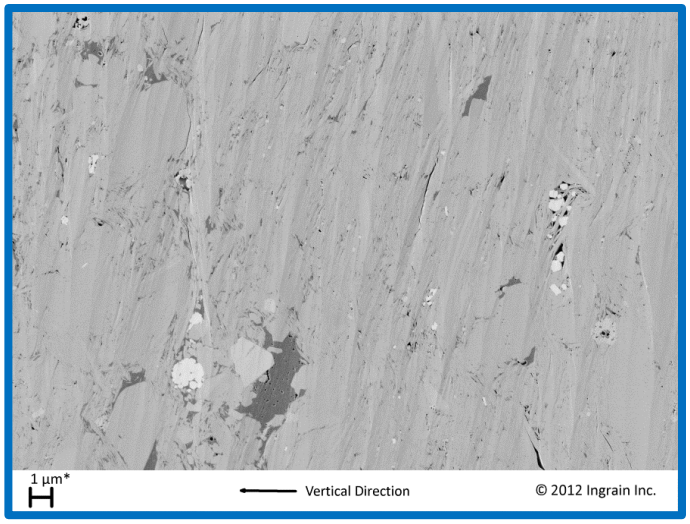
Sample Selection for Reservoir Quality Analysis (Stage 2 and 3) using CoreHD™ Facies

ANH







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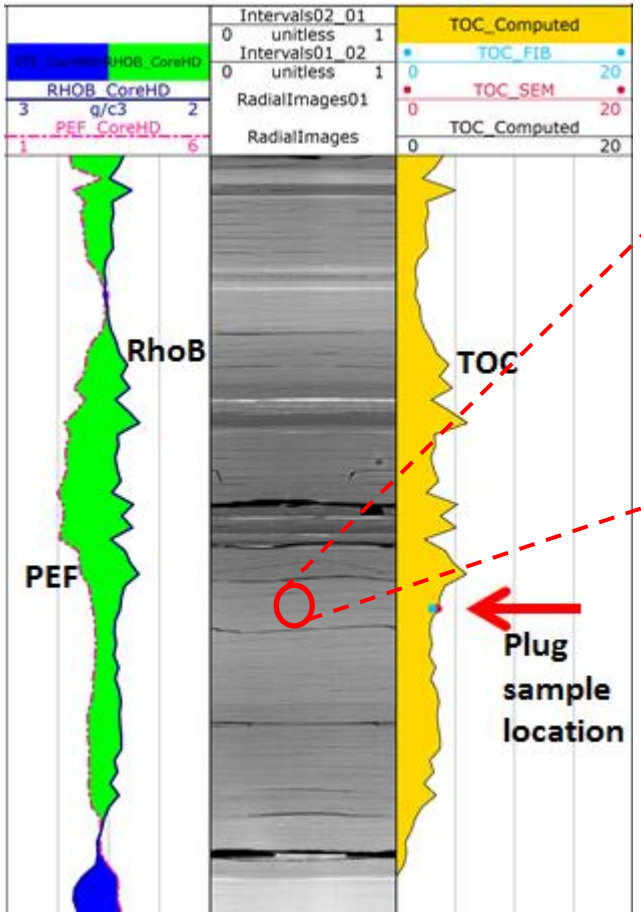
Stage 2: Plug-size sample analysis proces

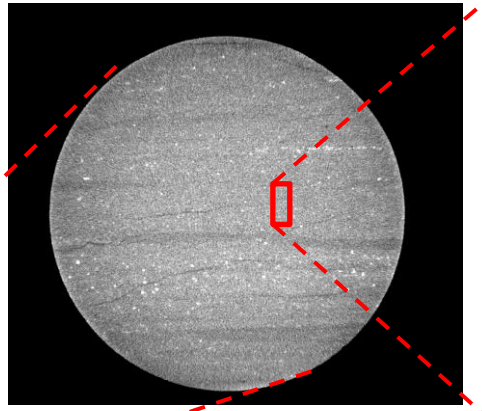
ANH

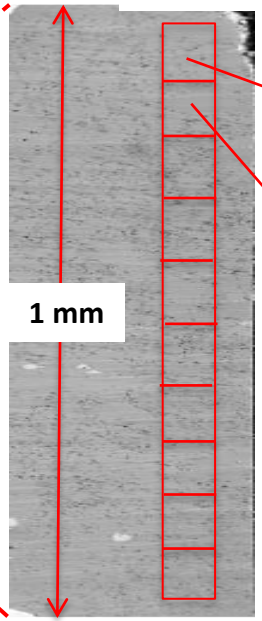
CoreHD™



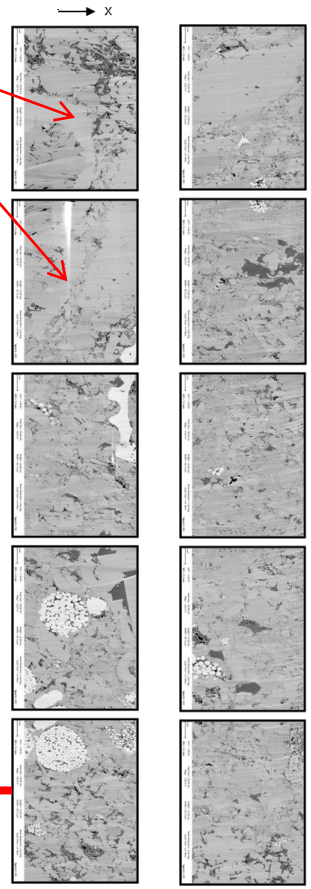
Micro CT

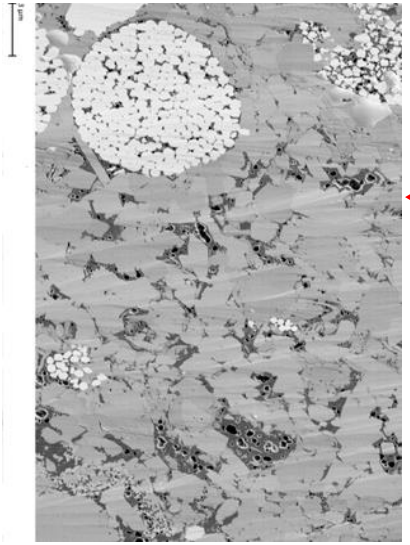
1” Diameter

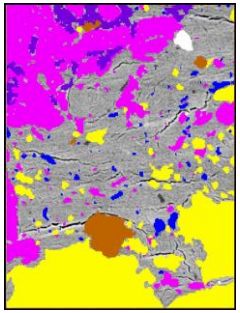




Milled SEM







EDS

Region selected for vRock™ 3D volume

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

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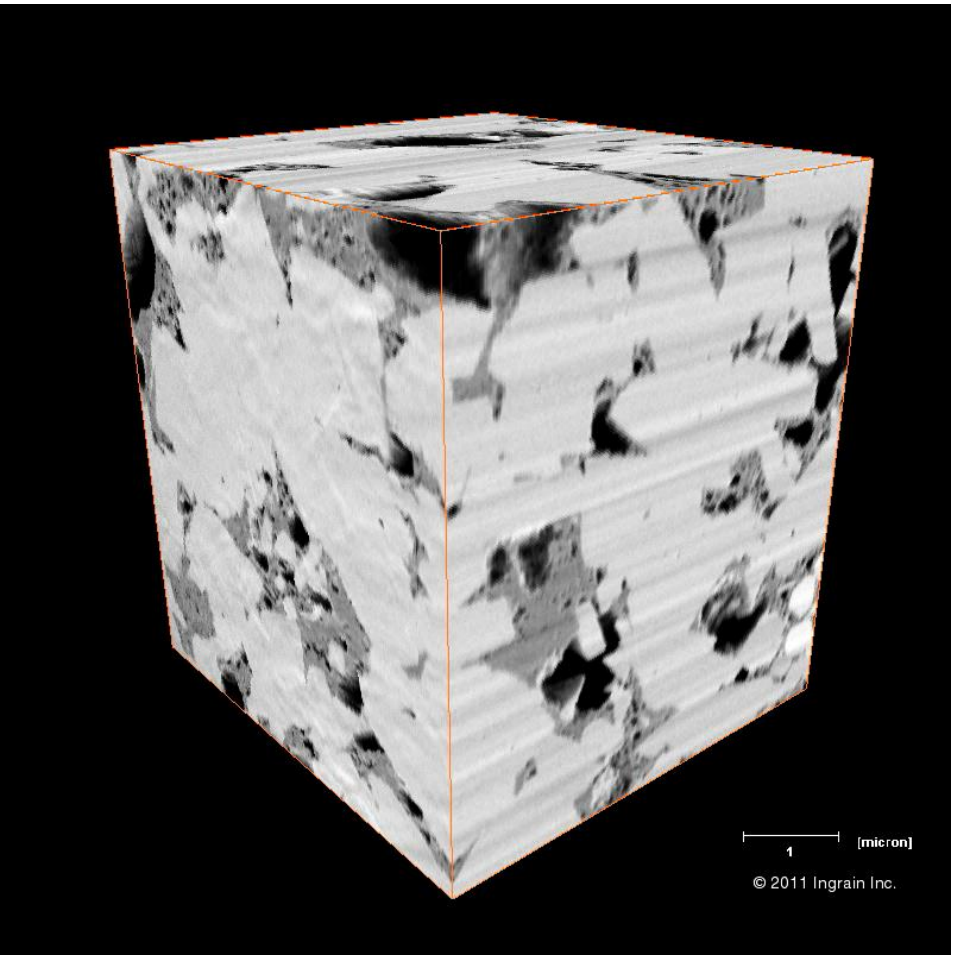
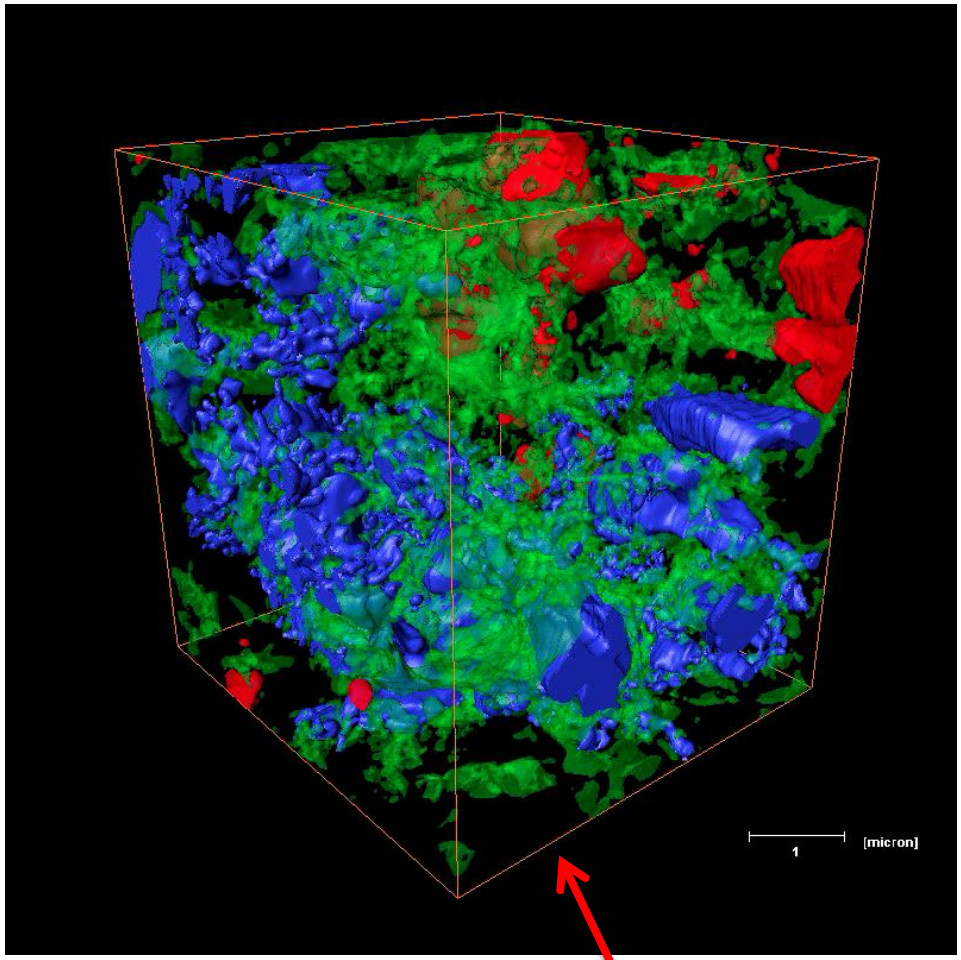
Red: isolated pores
Blue: connected pores
Green: organic material





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

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

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Understanding Shale Pore Types

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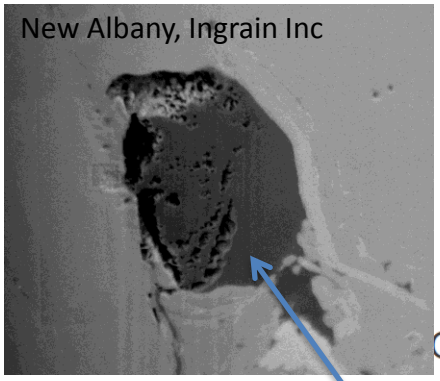
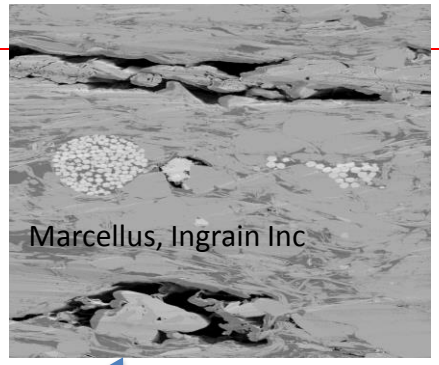
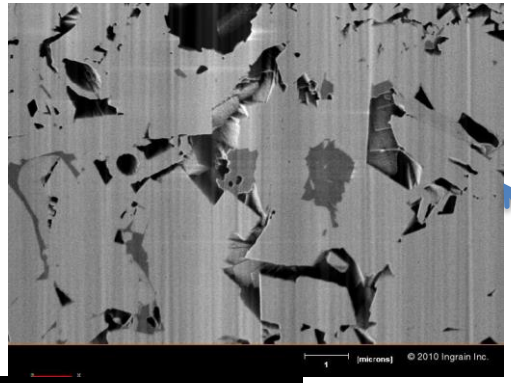
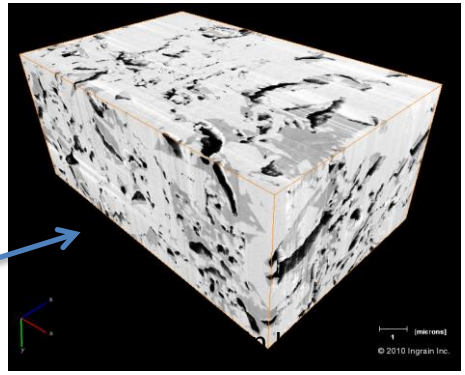
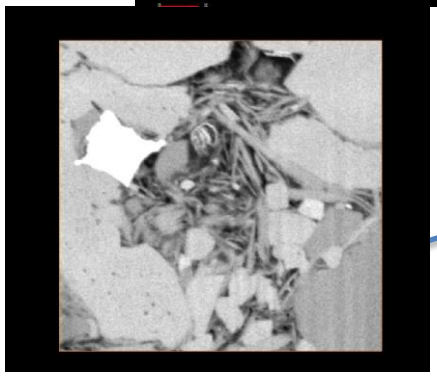




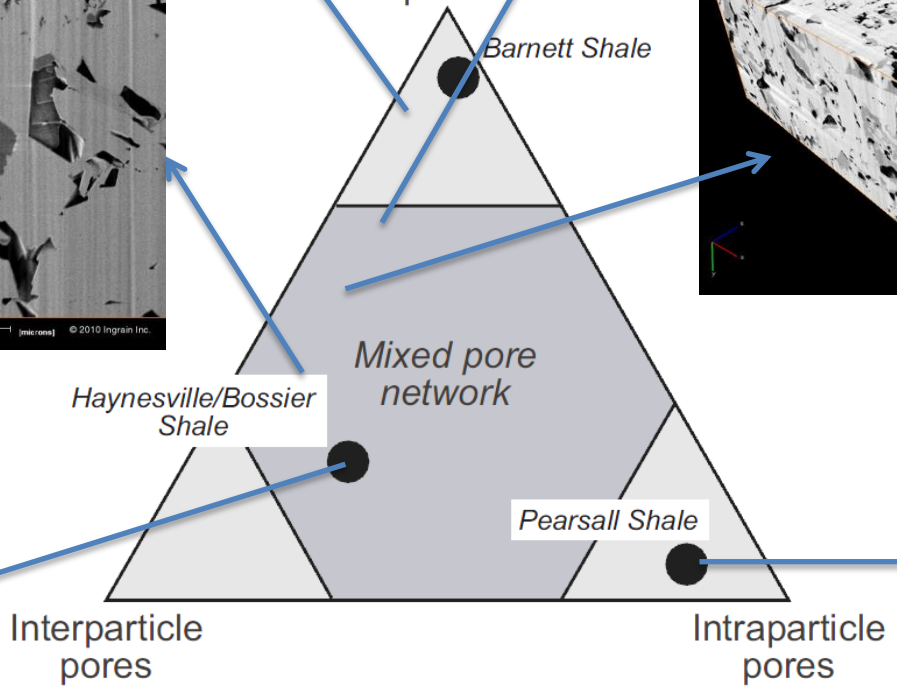
Niobrara, Ingrain



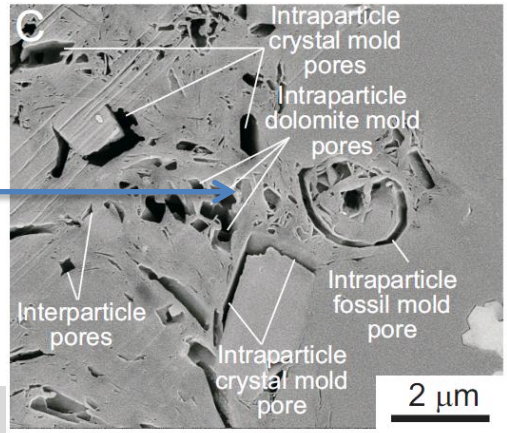




Haynesville, E.TX, Ingrain



Pearsall Shale, S. TX (Loucks, 2010)



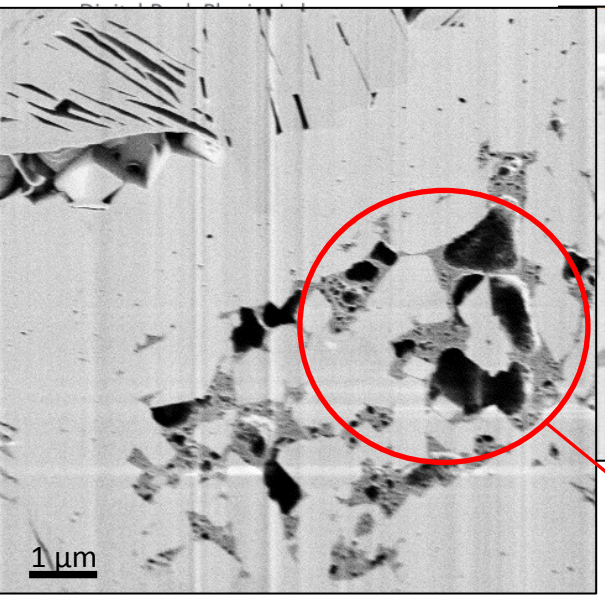
From Loucks, et al, GCAGS, April 2010

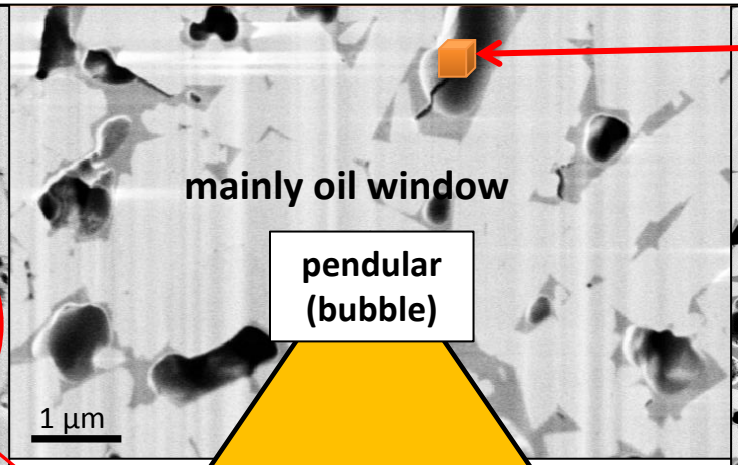
Understanding Organic Porosity Texture

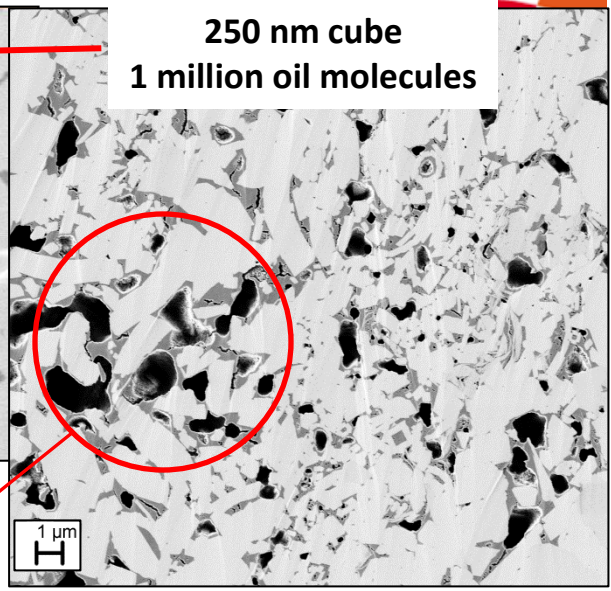
INGRAIN

ΔNH

250 nm cube
1 million oil molecules



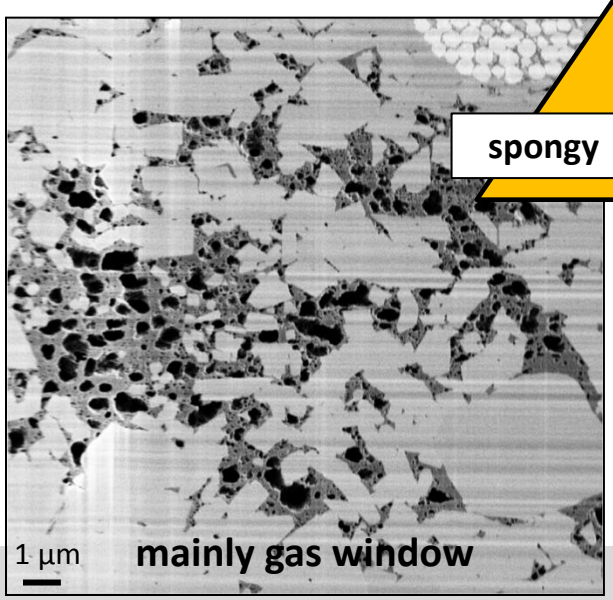


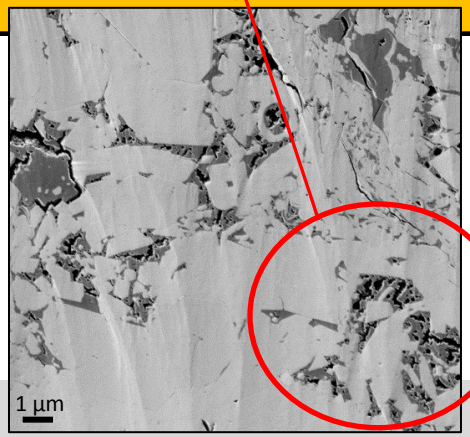


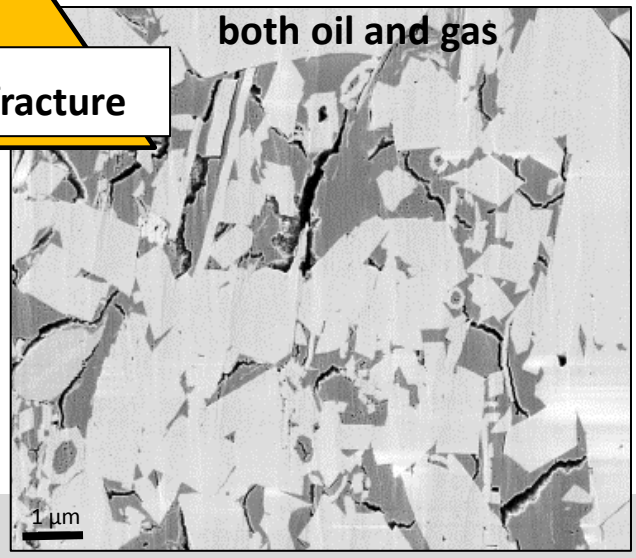
pendular (bubble)

spongy

fracture







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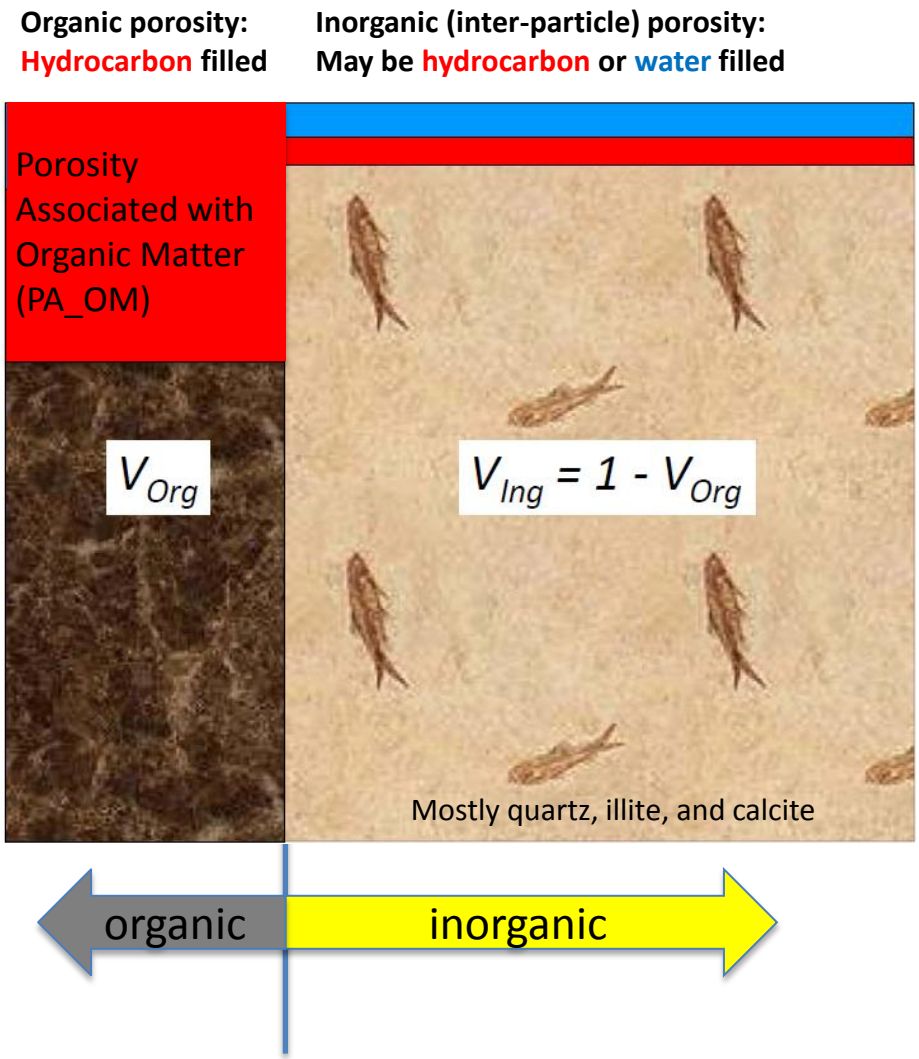
Ingrain Conceptual Rock Model* for Organic Mudstones

ANH

- 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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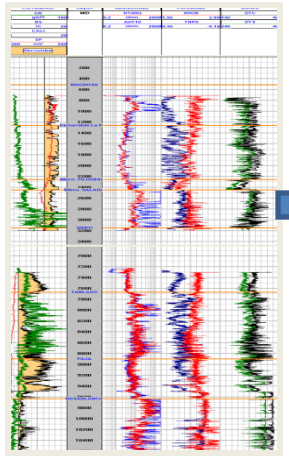
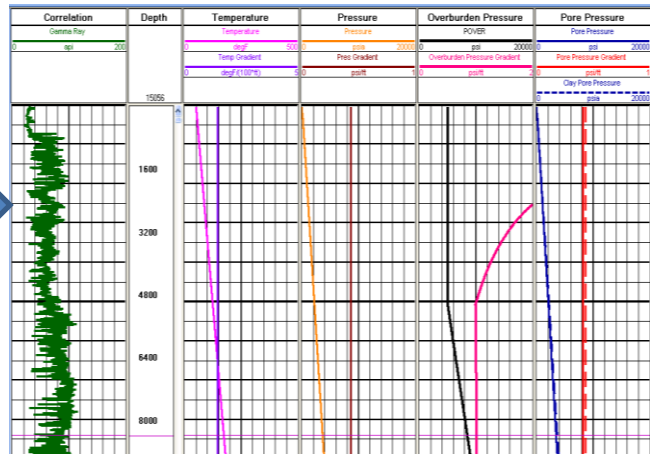
ANH

Petrophysical Methodology: *ShaleXpert*

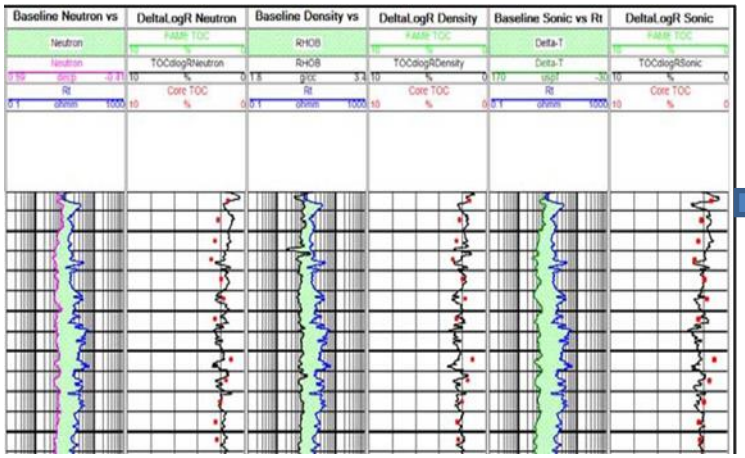
Edit and QC of logs



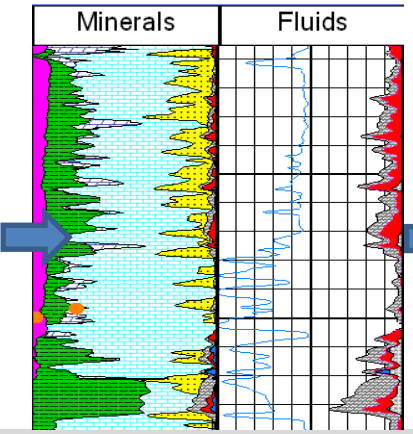
Temperature and pressure gradients



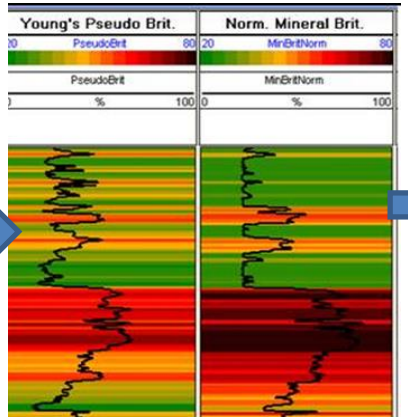
Estimate TOC and organic matter volume from logs and calibration to core



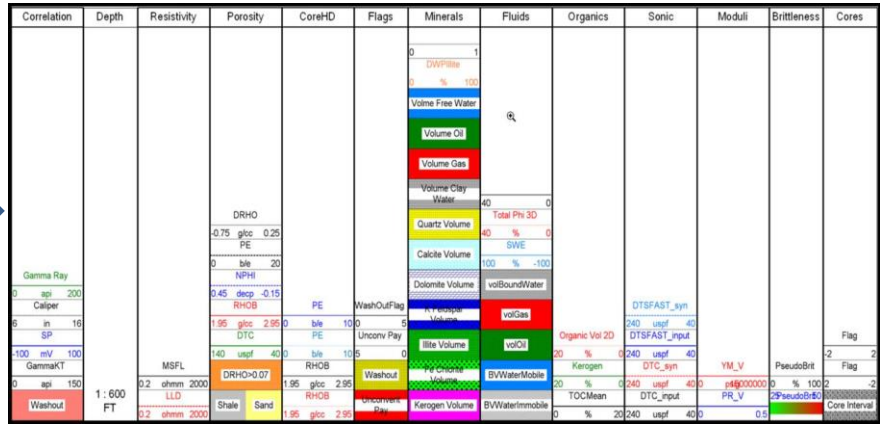
Probablistic estimation of porosity and fluids



Compute geomechanical properties, ie brittleness

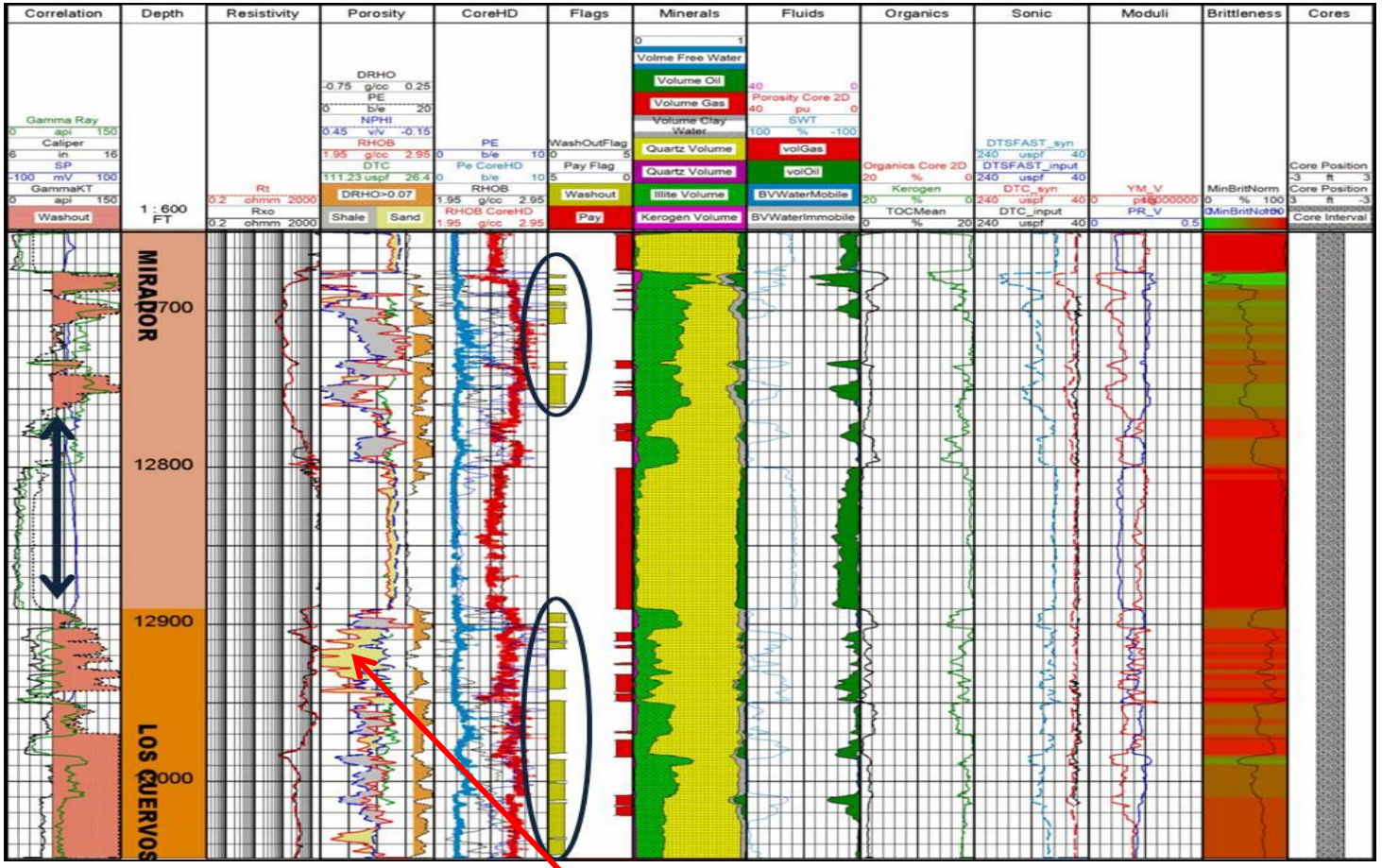


Integrated *ShaleXpert output*



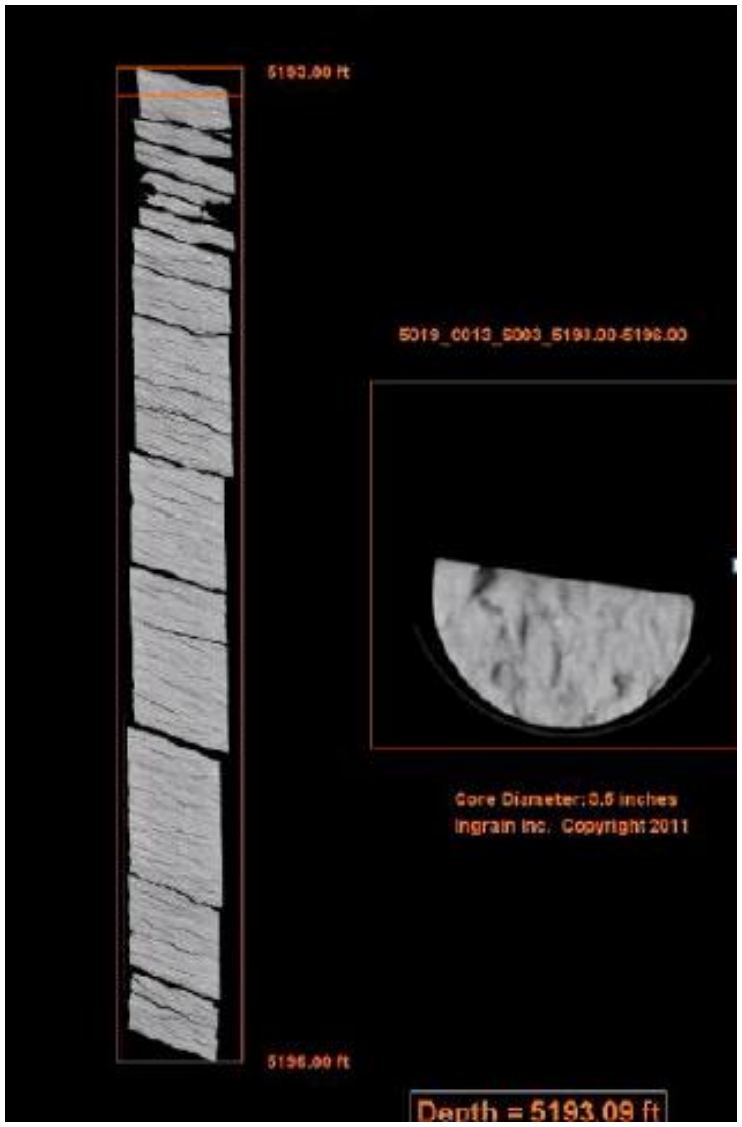
Petrophysical Methodology: *ShaleXpert*

Final Output Example



KEY RESULTS AND FINDINGS

Examples: Whole Core CT Imaging



- 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 Infantas-1613 well, VMM Basin

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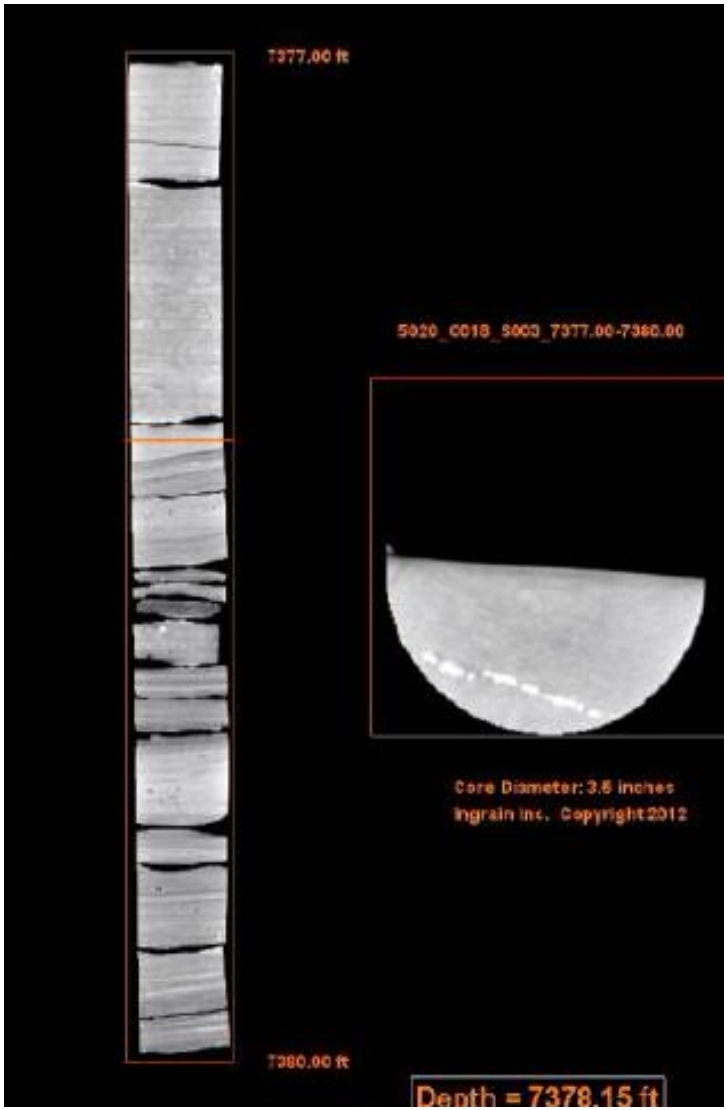
Examples: Whole Core CT Imaging

ANH



- 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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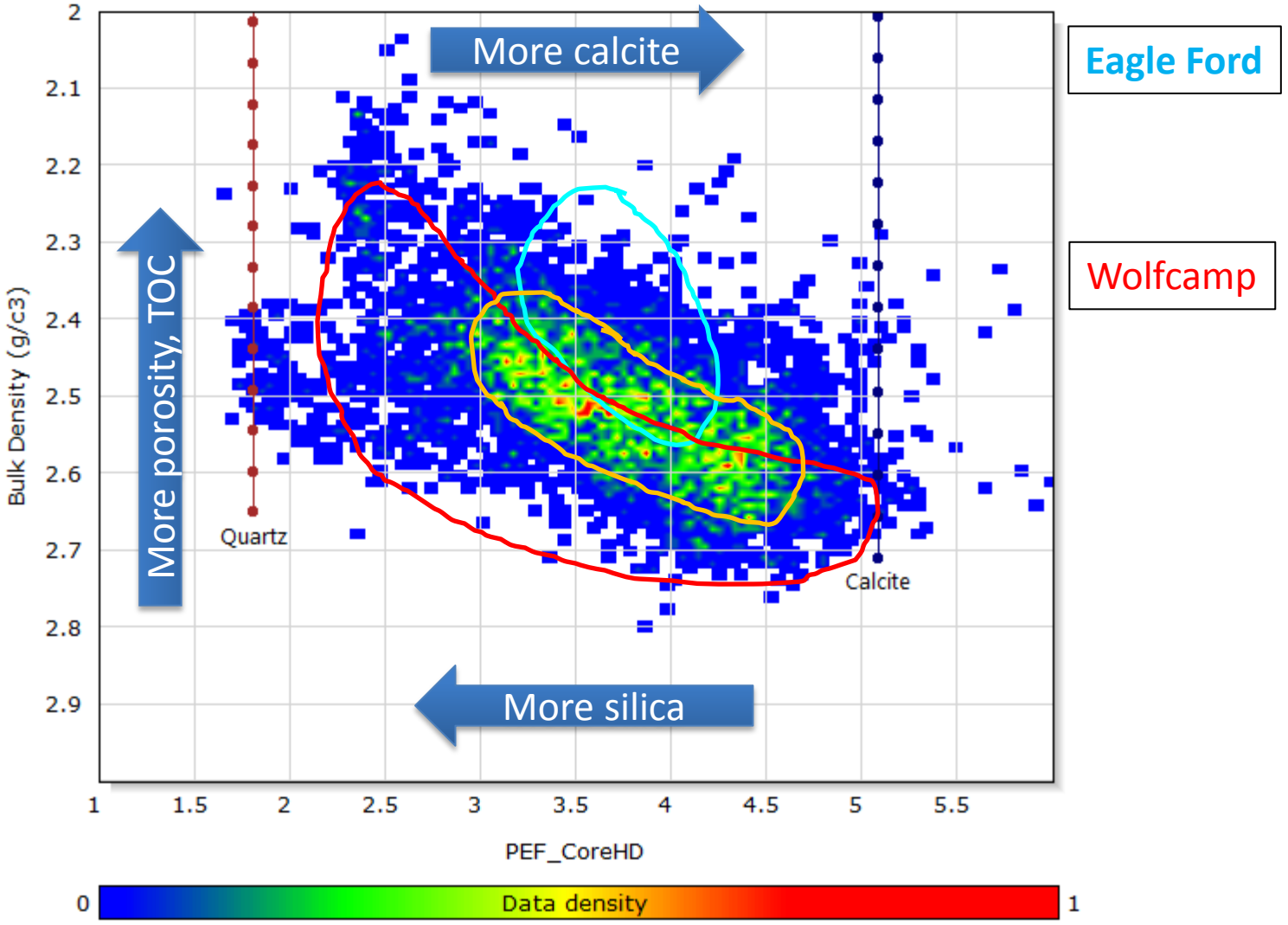
CoreHD™ Litho-density Analogs:



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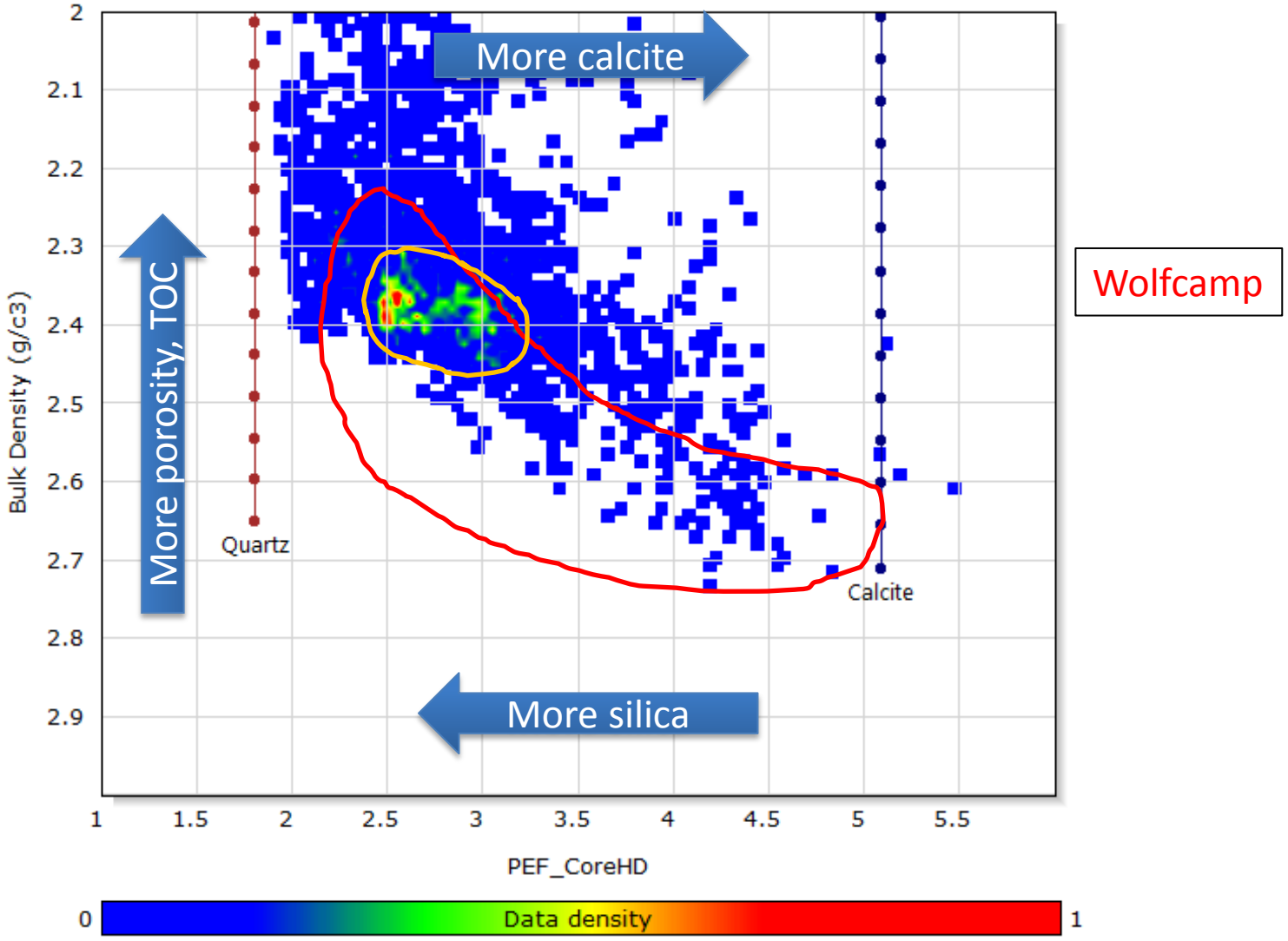
CoreHD™ Litho-density Analogs: VMM - La Luna



Wolfcamp

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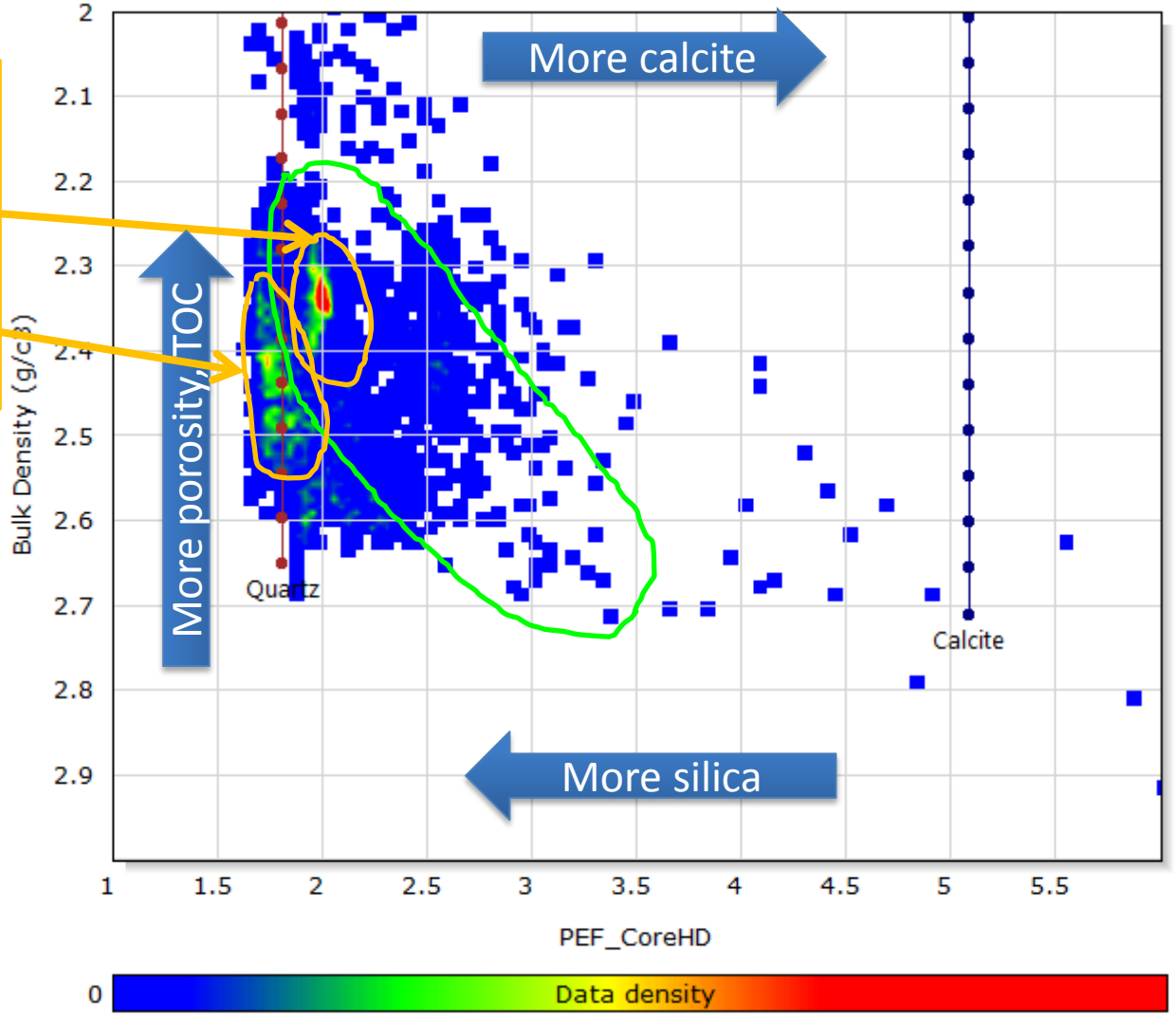
CoreHD™ Litho-density Analogs: Llanos – Gacheta (organic regions)

ANH

Note presence of organic shale and clean sand/silt intervals



Fayetteville

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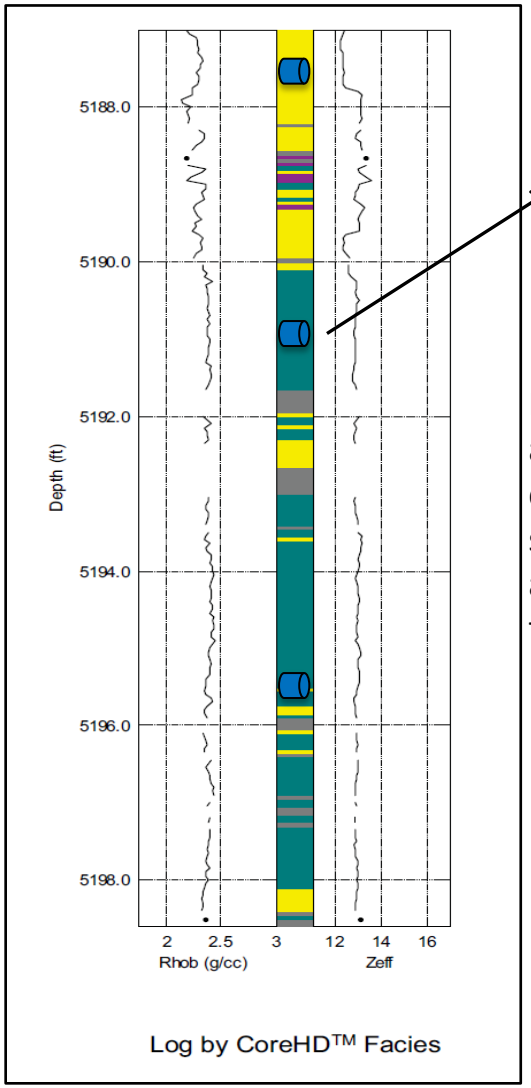
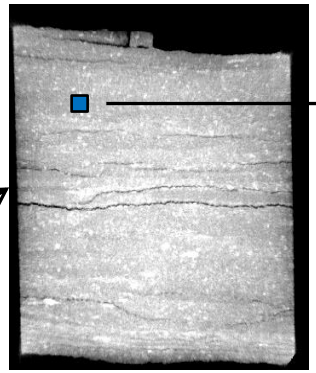
Examples: Sample selection, Micro CT & 2D SEM Imaging

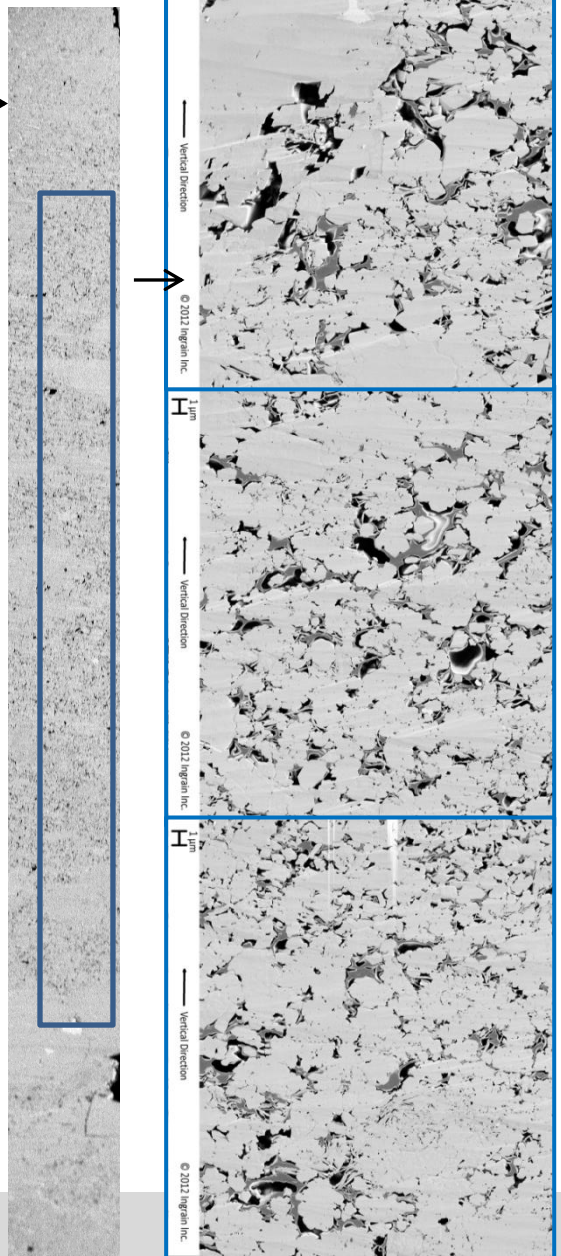
ANH
AGENCIA NACIONAL DE HIDROCARBUROS
COLOMBIA



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 to create a polished surface.

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

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

HALLIBURTON

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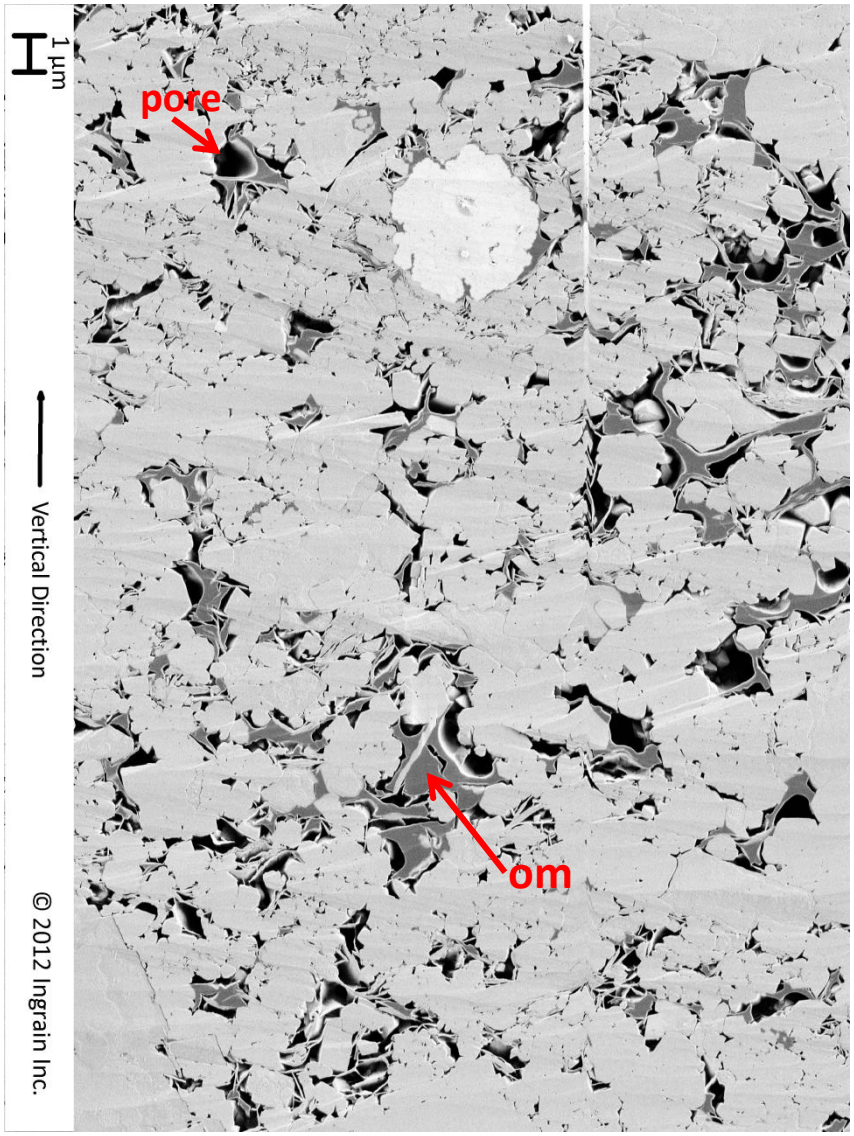
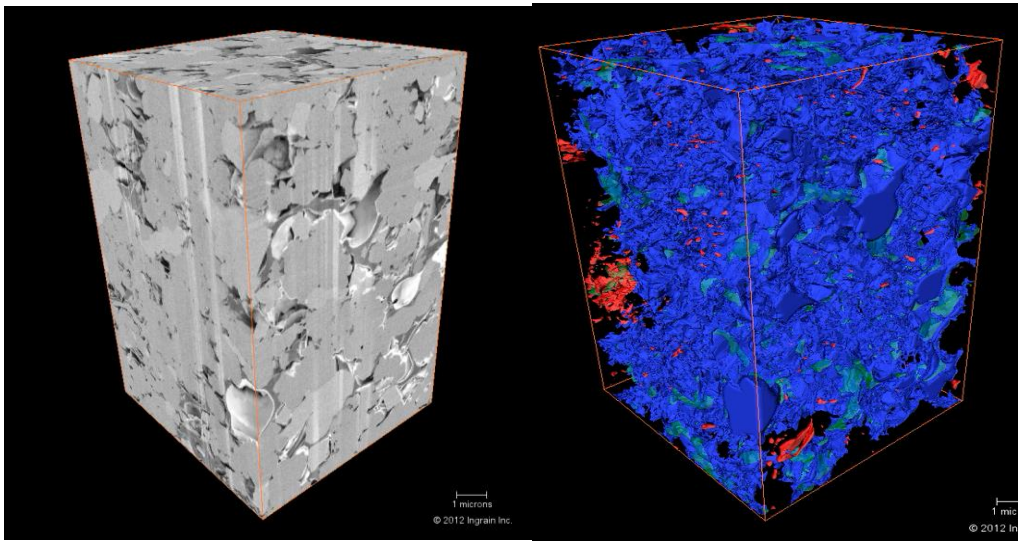
Examples: 3D SEM Imaging

ANH





Surface of 3D FIB-SEM Volume Pore Volume

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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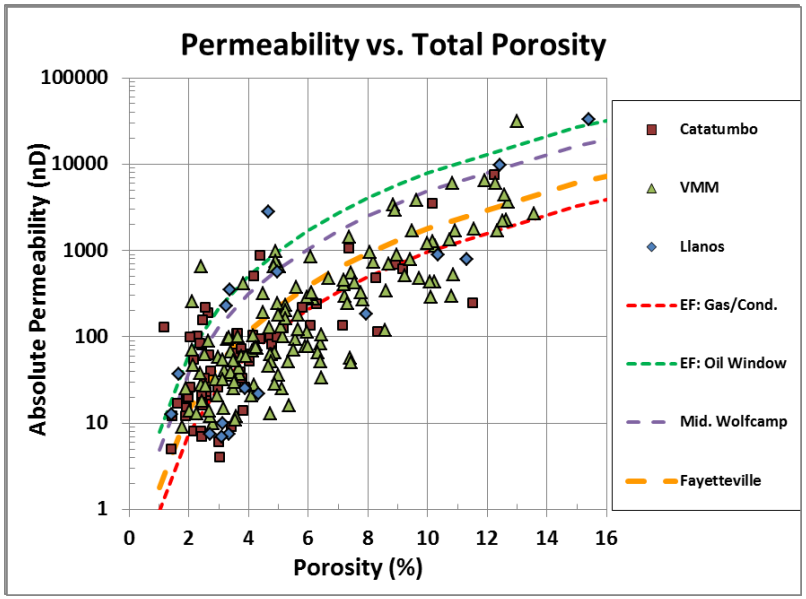
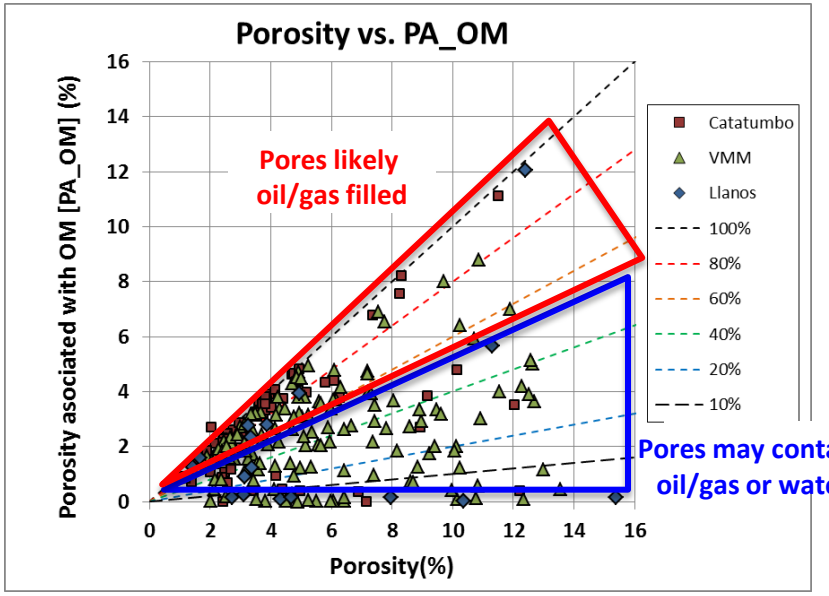
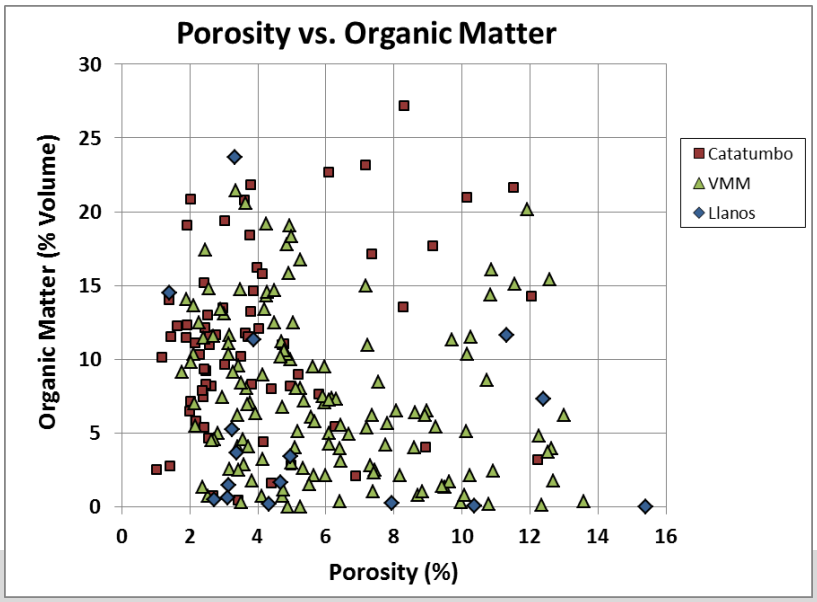
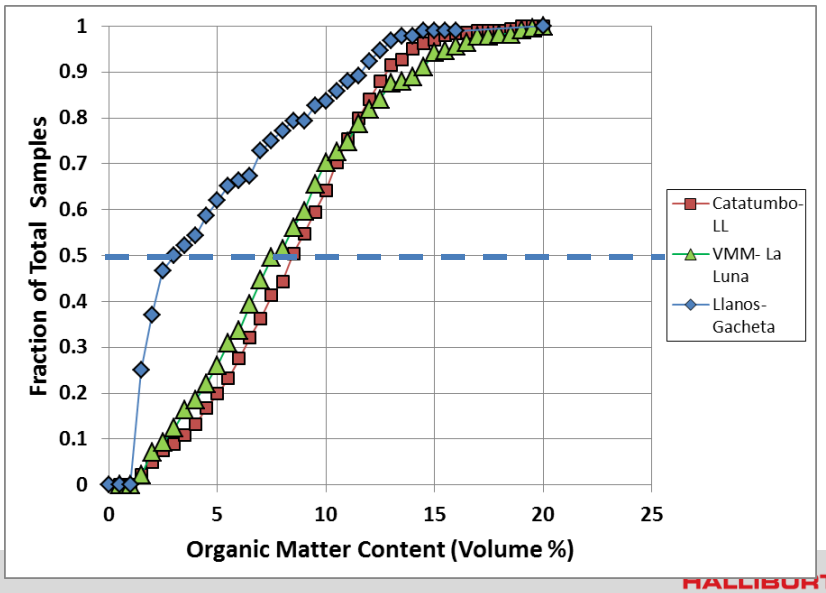
Rock Quality Analysis – 3 Basins- 2 Formations (La Luna, Gacheta)

ANH









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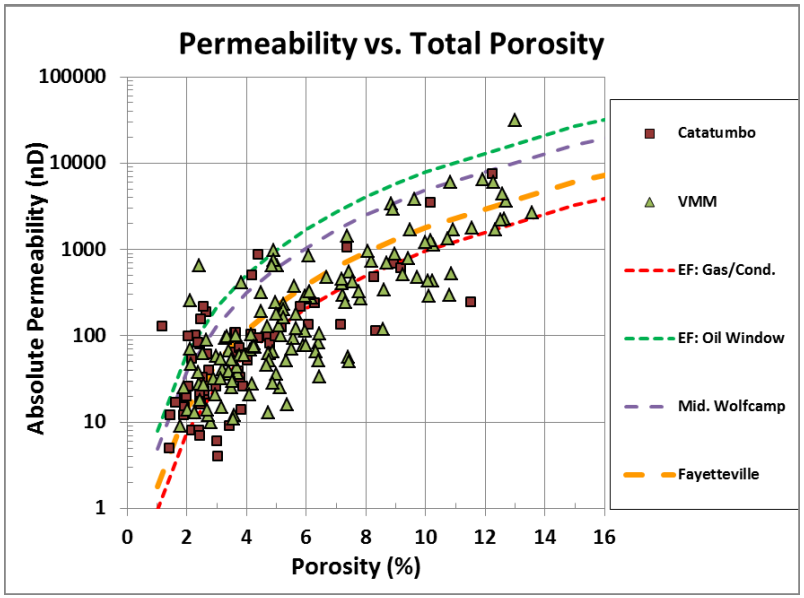
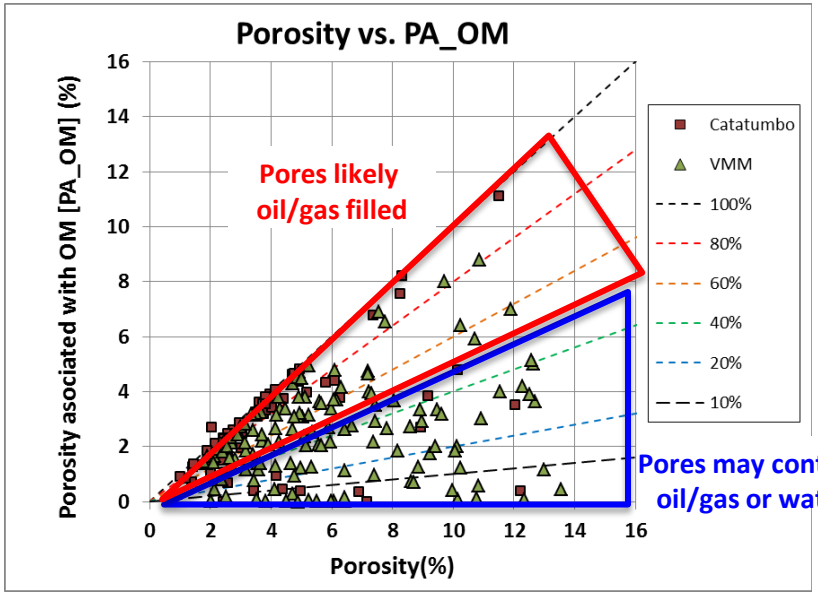
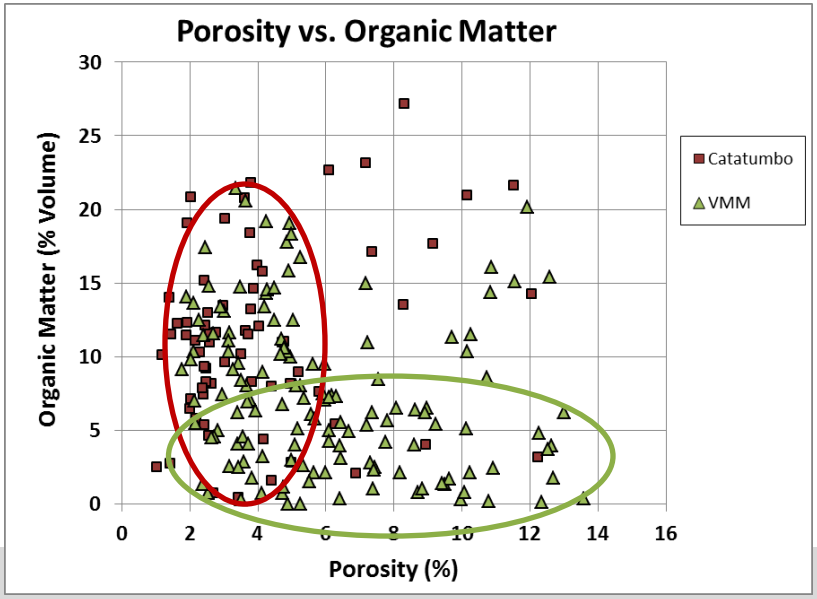
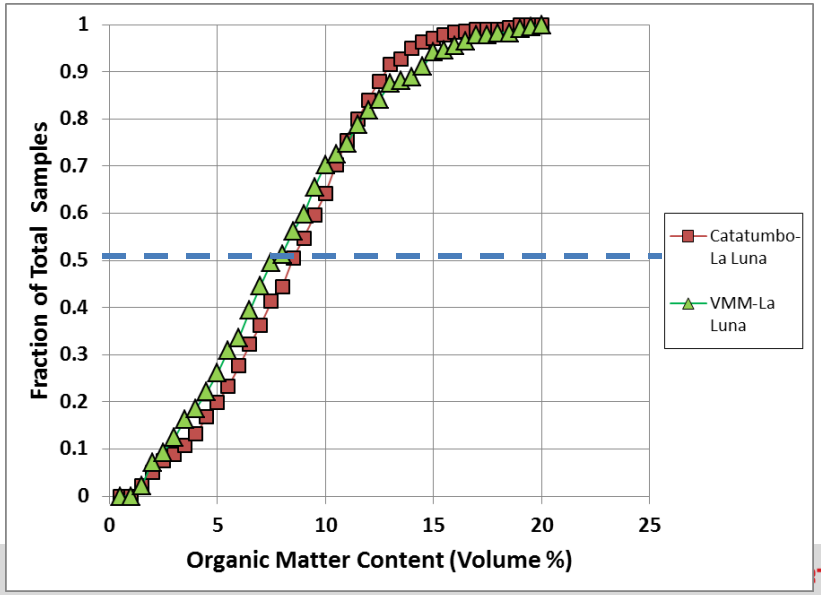
Rock Quality Analysis – La Luna Fm

ANH









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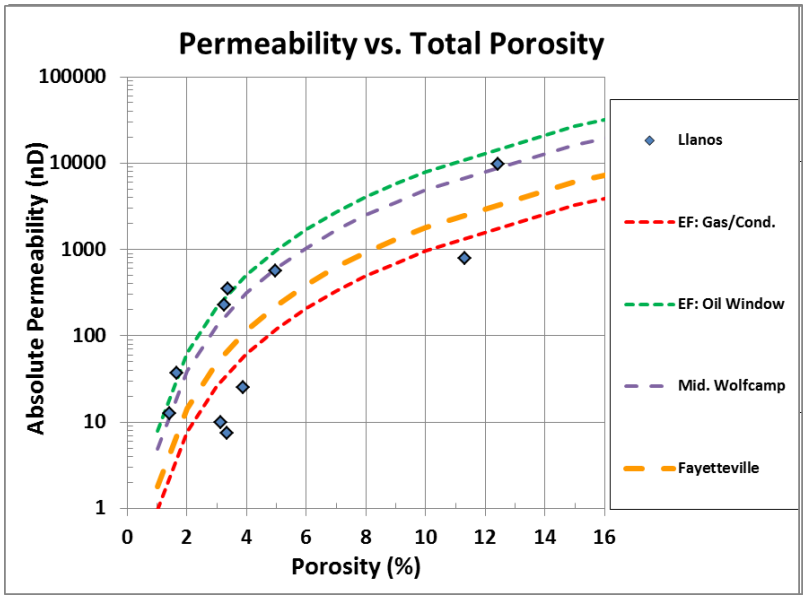
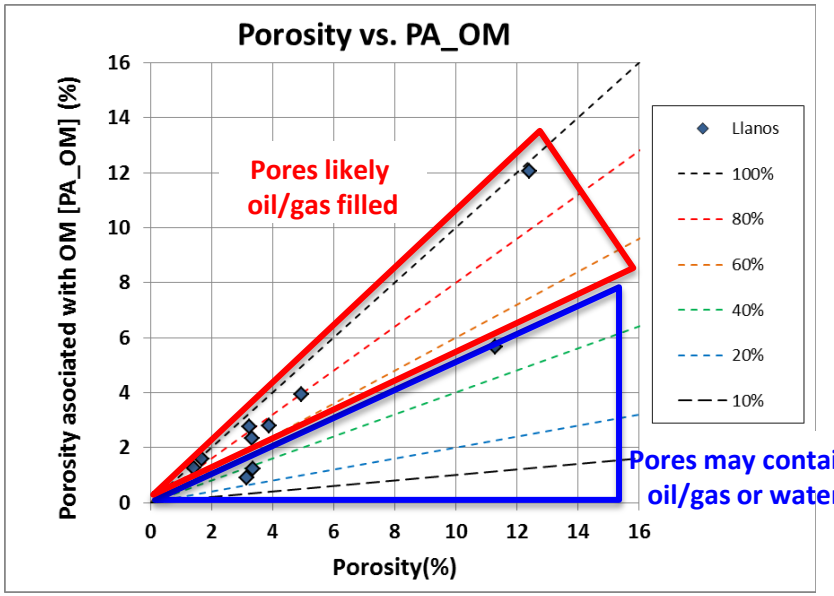
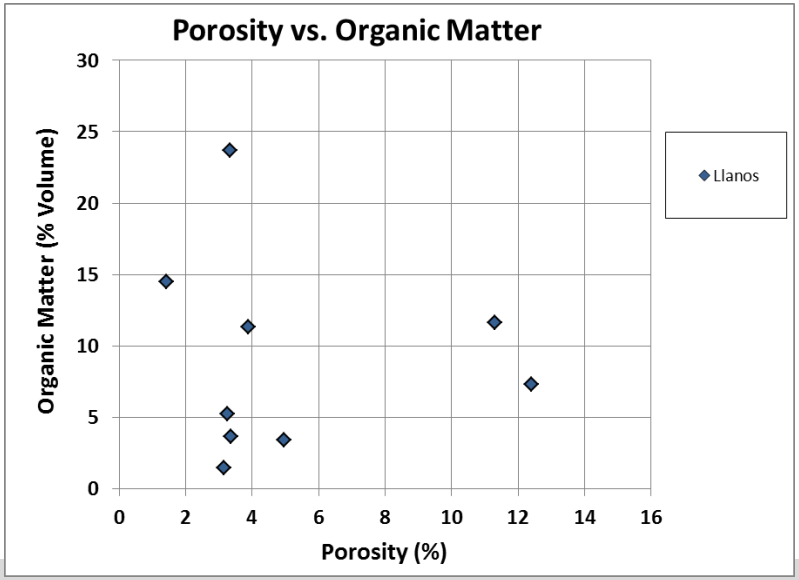
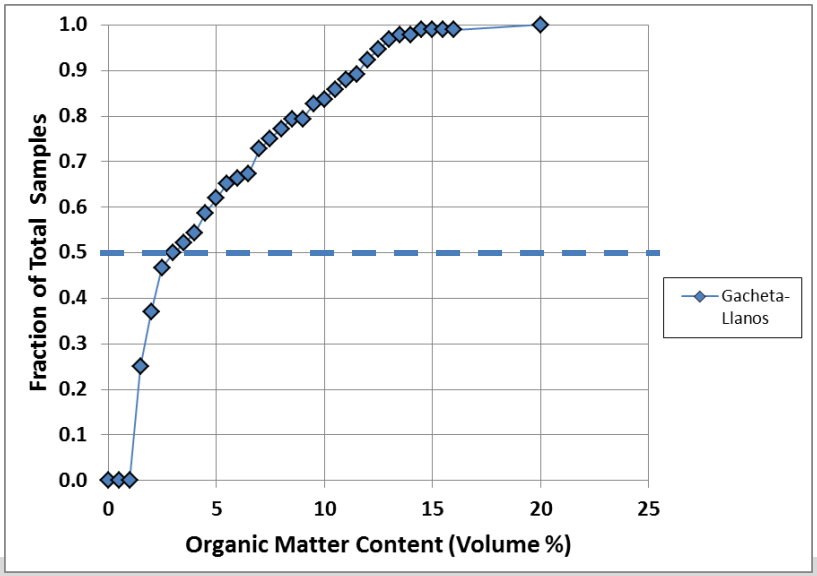
Rock Quality Analysis – Gacheta Fm (2 wells only)

ANH









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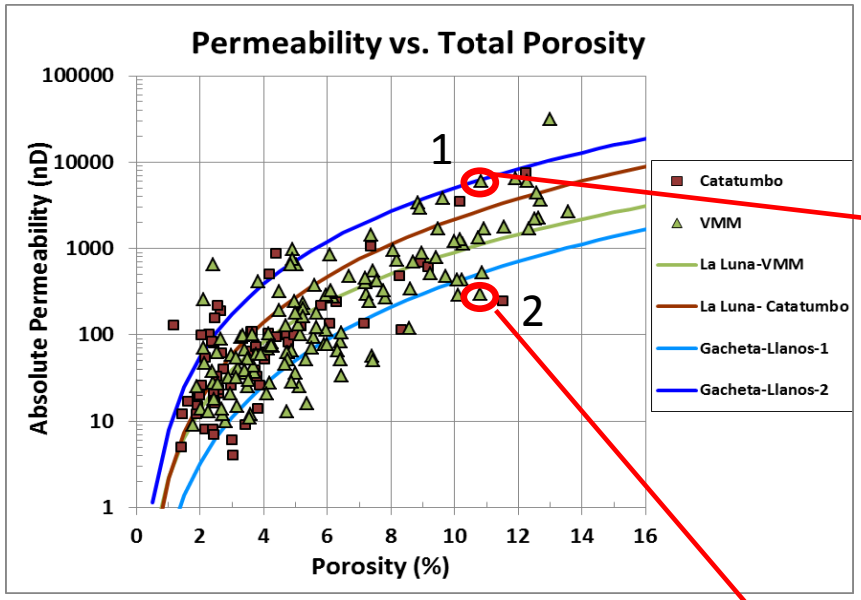
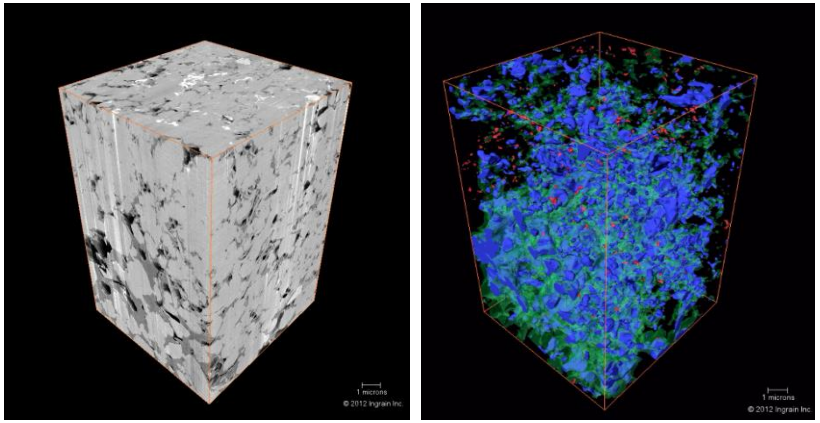
VMM: Infantas-1613 - Differences in Permeability Related to Pore Types and Sizes

ANH



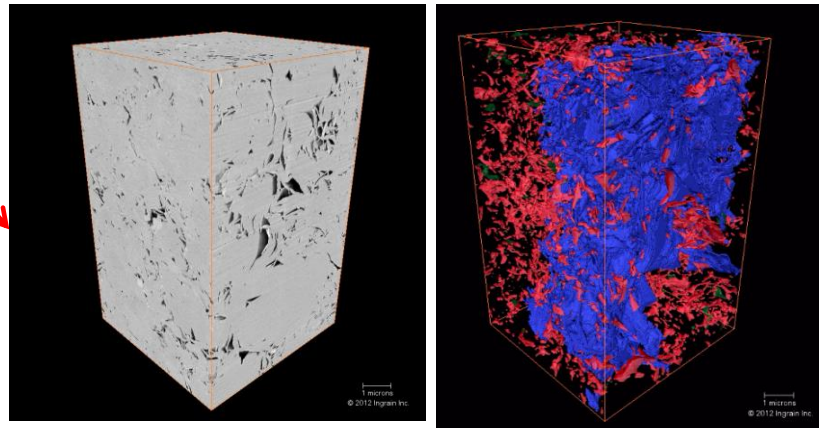
- Sample 1 and 2 have similar porosities, but their permeability values differ.
- Sample 1 contains more PA_OM and is connected through the OM. This sample has the highest permeability
- Sample 2 contains mostly intergranular porosity

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

Rock Quality Analysis – 3 Basins- 2 Formations

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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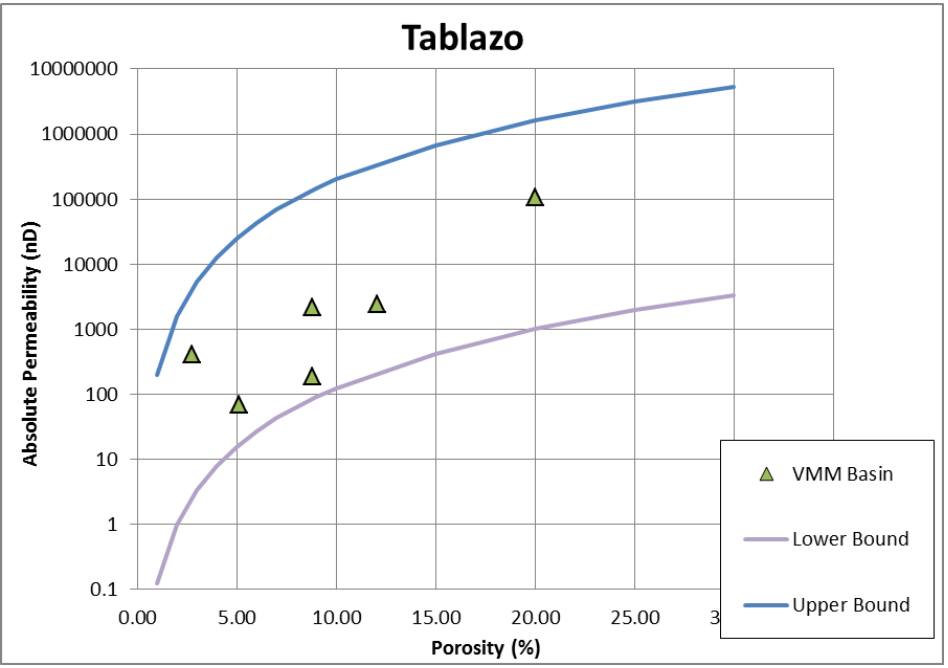
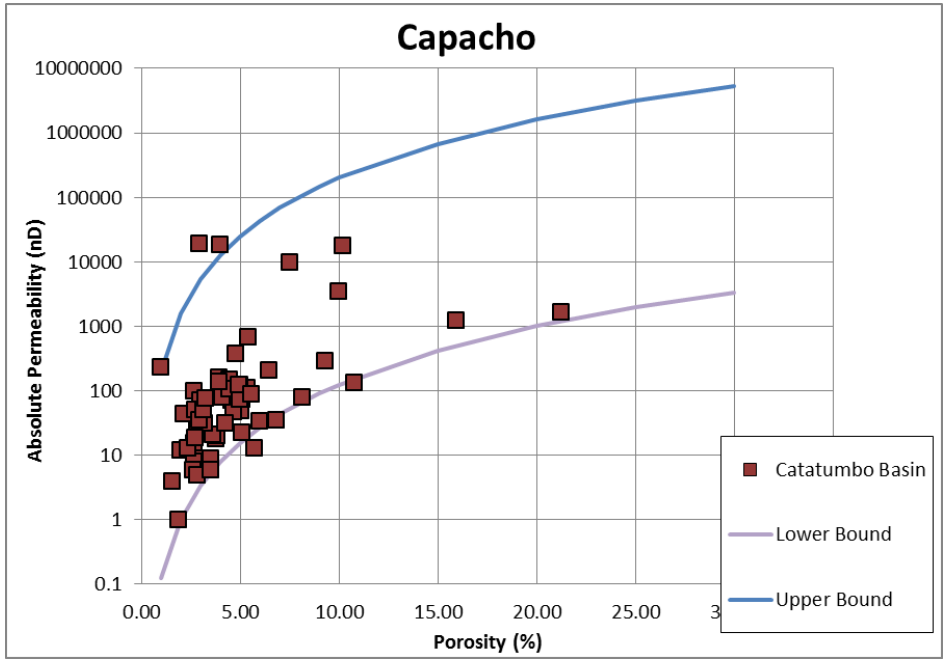
Limited Data but with Good Resource Potential

ANH



VMM



Catatumbo

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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
- Formation with good potential but limited data: Tablazo (VMM), Capacho (Cat.), Paleozoic sequence, Llanos (based on ShaleXpert results from Carrizales 9)

Gracias!