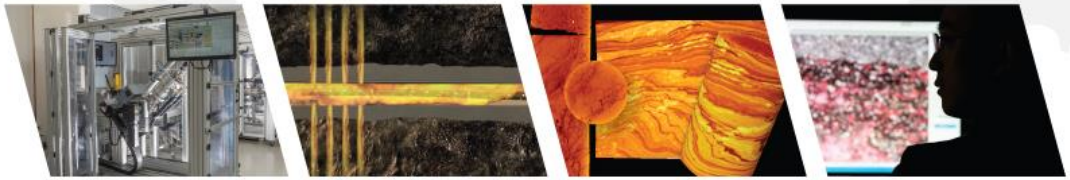
Society of Petrophysicists and Well Log Analysts
Qatar Chapter
Virtual Series - 8th March 2021

X-RAY Rock Characterization

Millimeter-Scale Log for Cored Intervals and Beyond

Max Podolyak - Technical Director/ SME Middle East
AJ Kumar, Ron Cormier, Tom Pugh- Core Laboratories USA

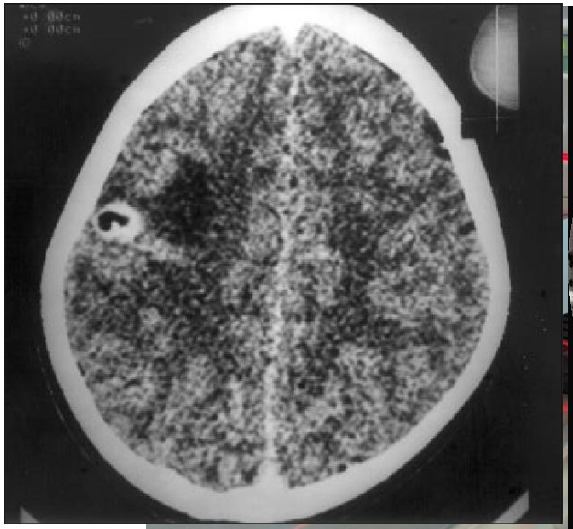
OVER 80 YEARS OF INNOVATION

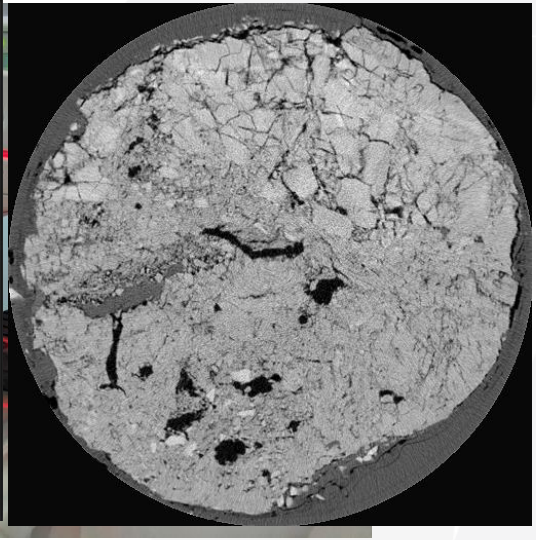


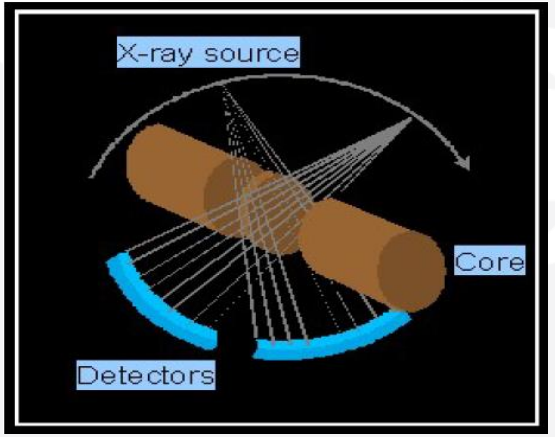
Agenda

- Core 3D Images, Interactive Access
- Core Petrophysical Characterization
- Automated sample selection
- Other Applications:
  - Density Mapping & Fracture Characterization
  - Net to Gross

Computed Tomography

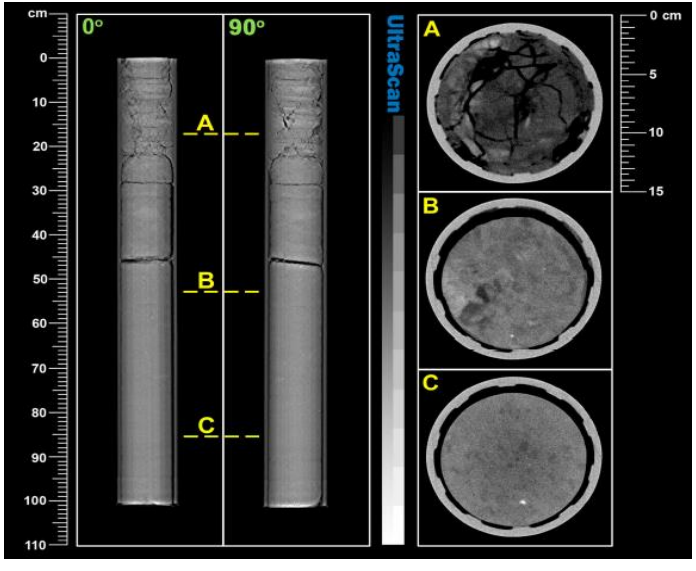


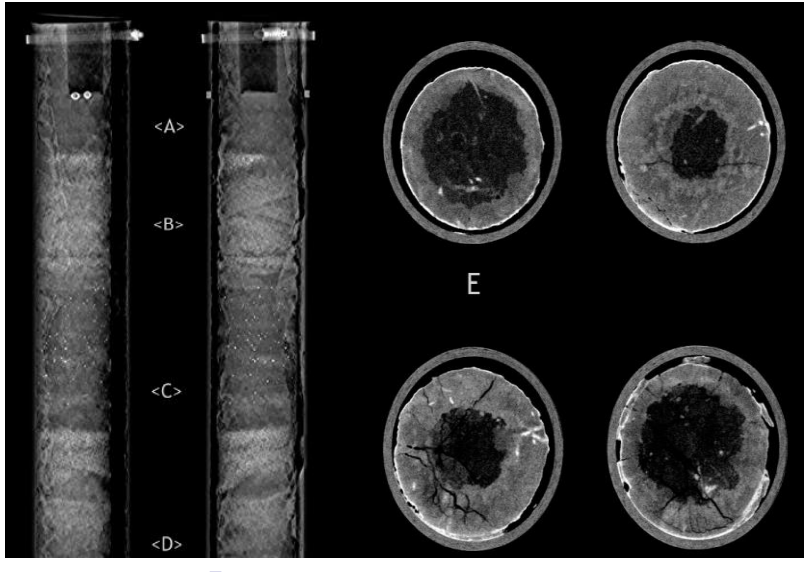


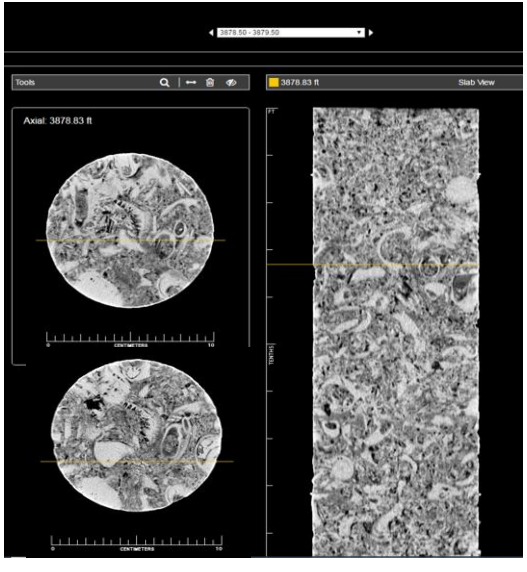


Conventional 1D X-Ray CT Scanning

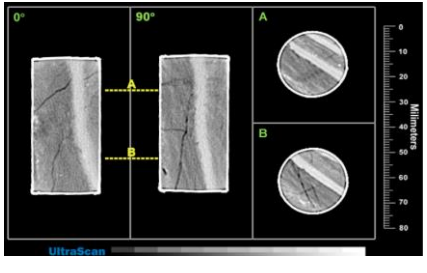
Whole Core Scans

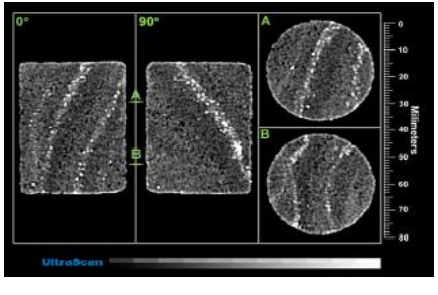






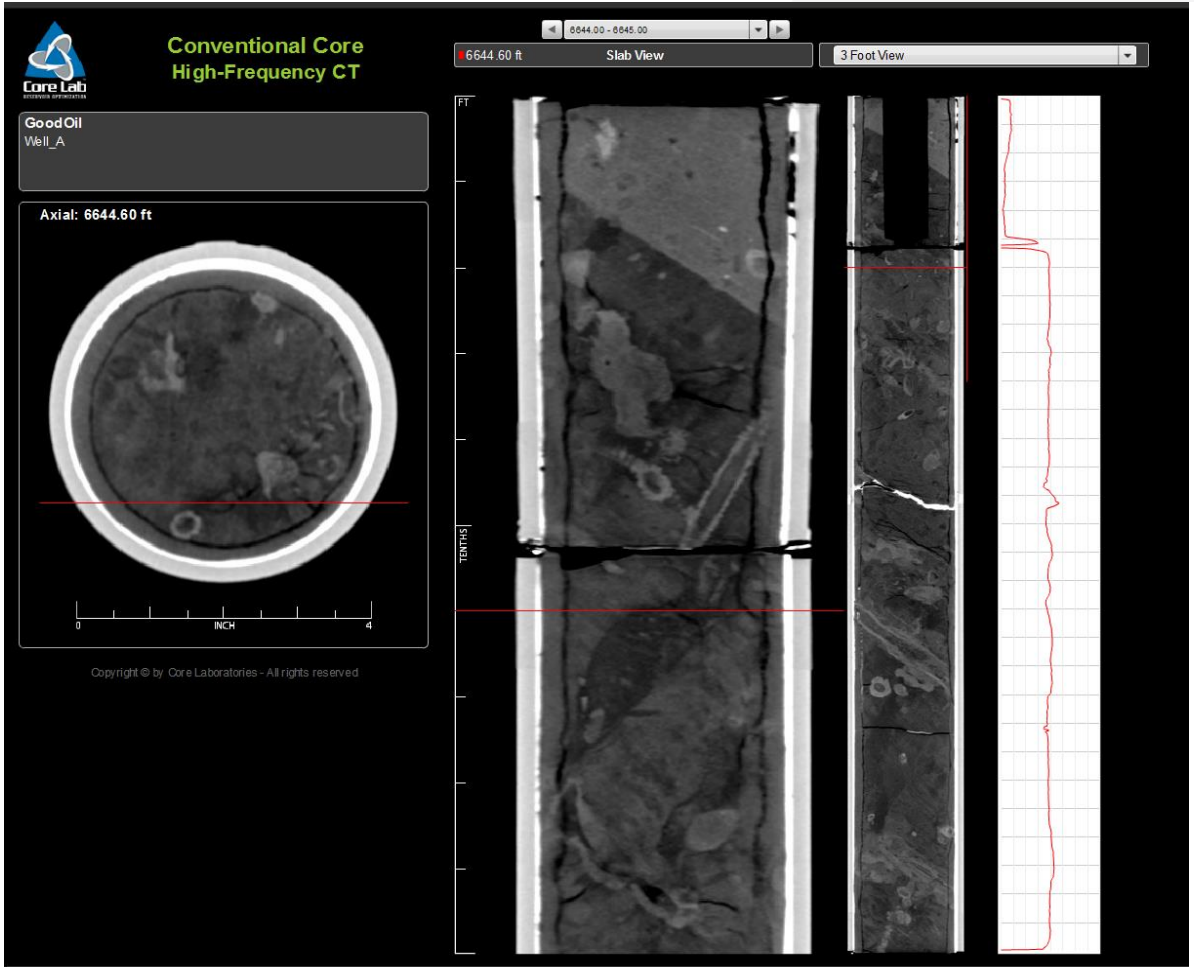
Core Plugs Scans





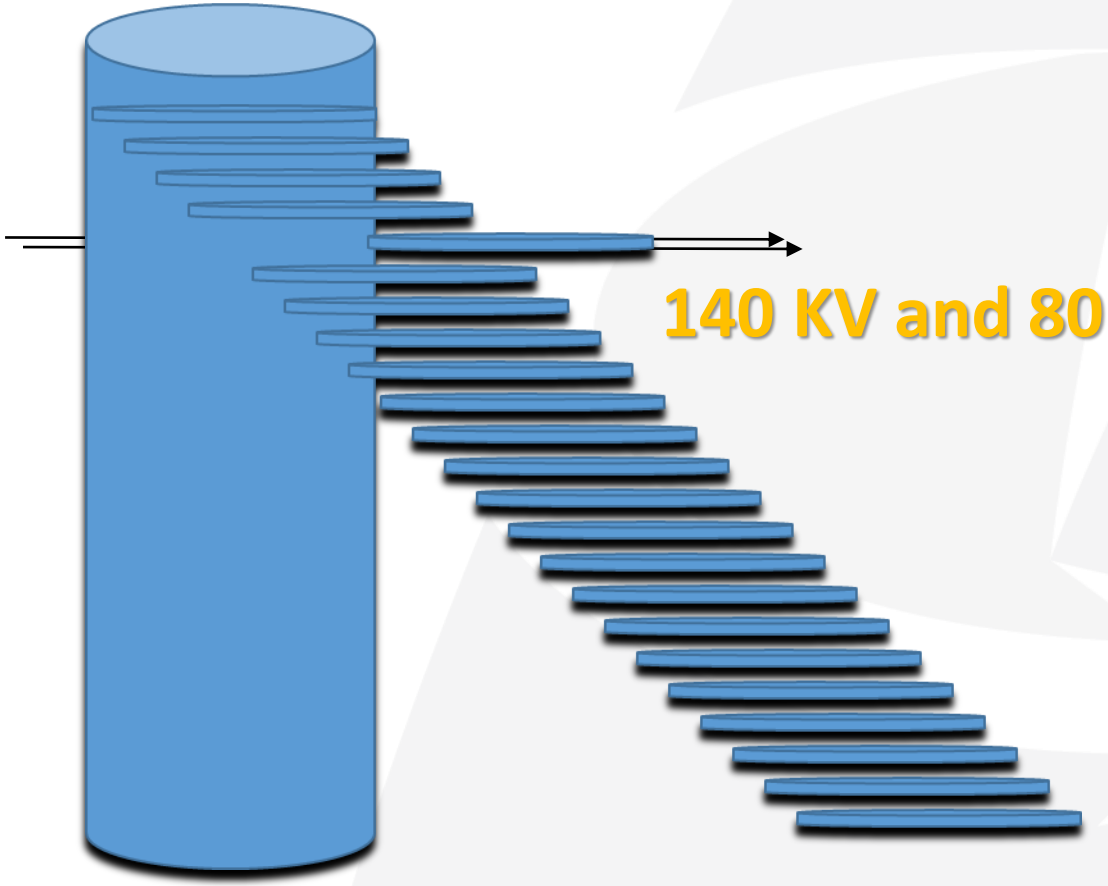
Helical 3D-VCT – Interactive Browser

- Fast Scanning - minutes
- Vertical Resolution 0.5mm
- DFOV resolution -0.25 mm
- Full 3D images
- Circumferential Images



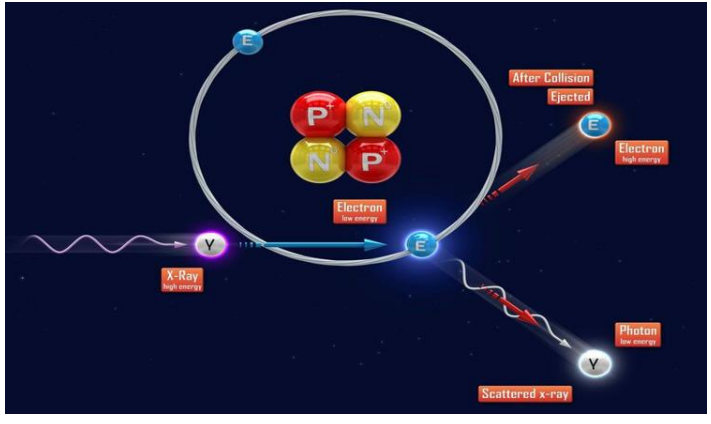
Dual Energy CT – Litho-Density Tool

Millimeter Scale Petrophysical Characterization

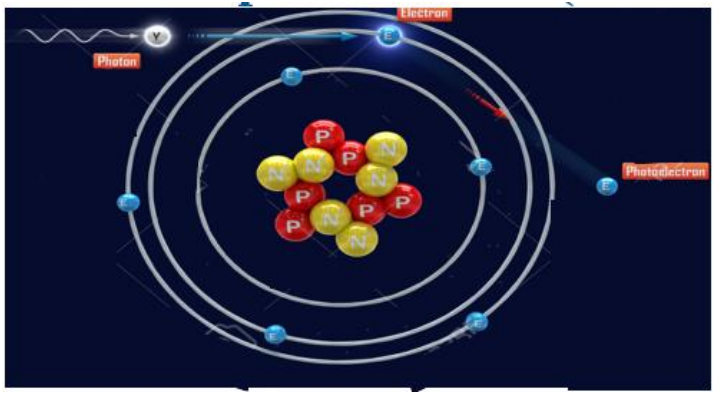


Dual Energy X-Ray Scanning

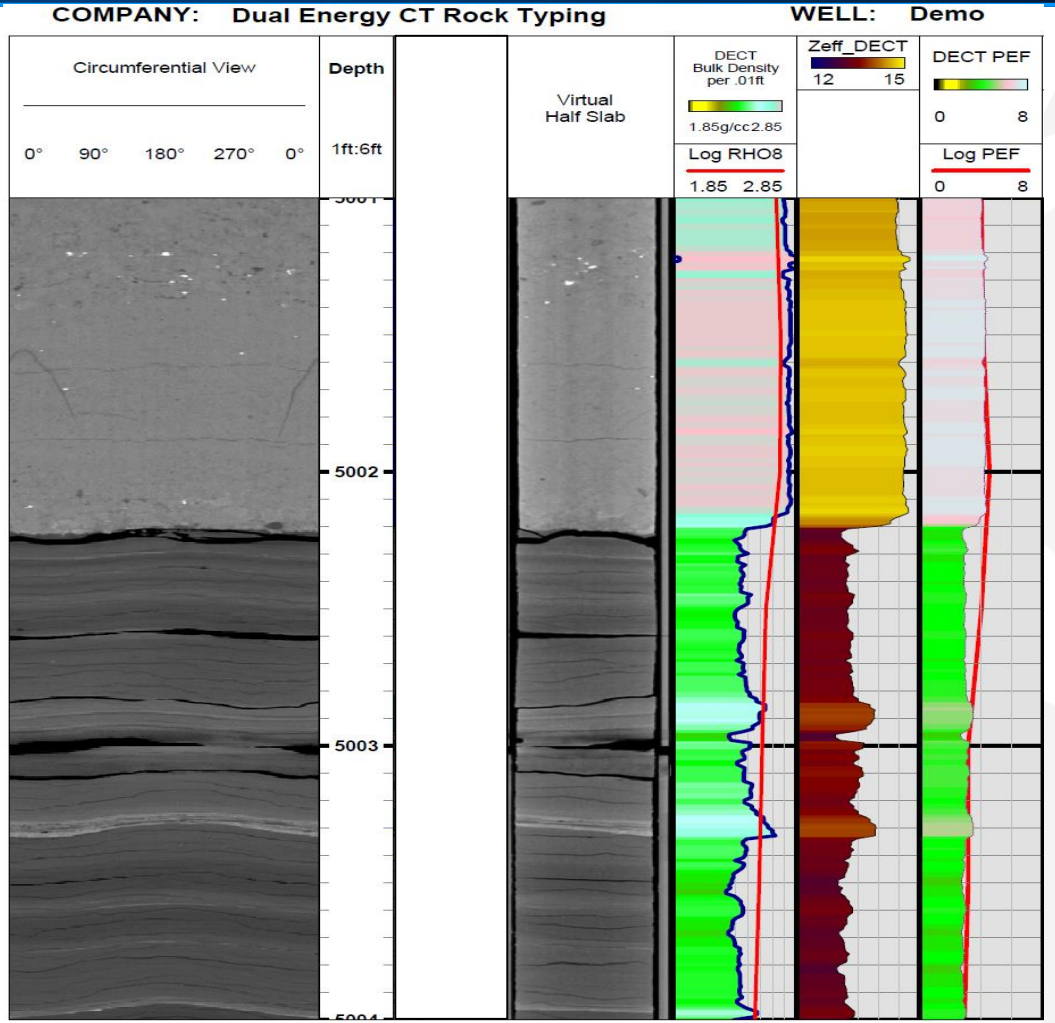
High kV=> Compton Scattering => Electron Density => Bulk Density



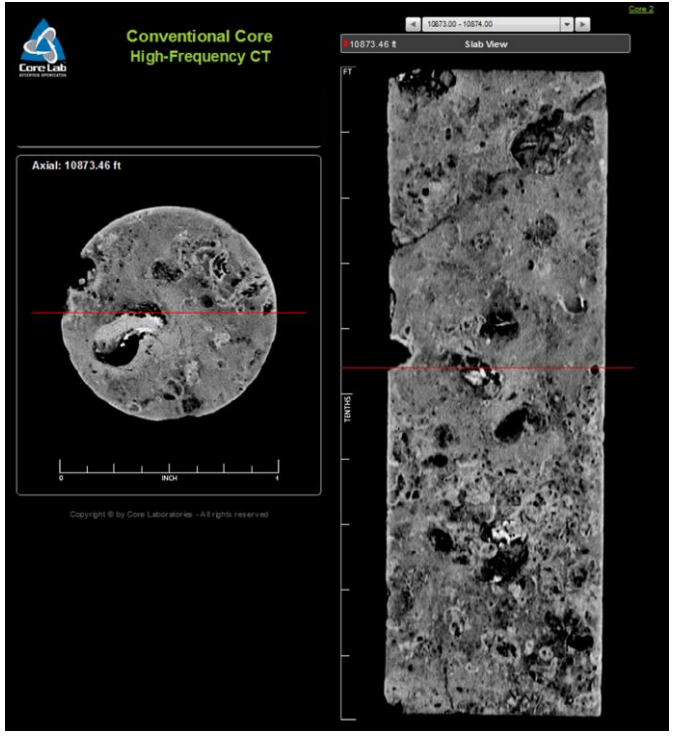
Low kV=> Photoelectric Absorption => Zeff (atomic number) => Rocks Composition

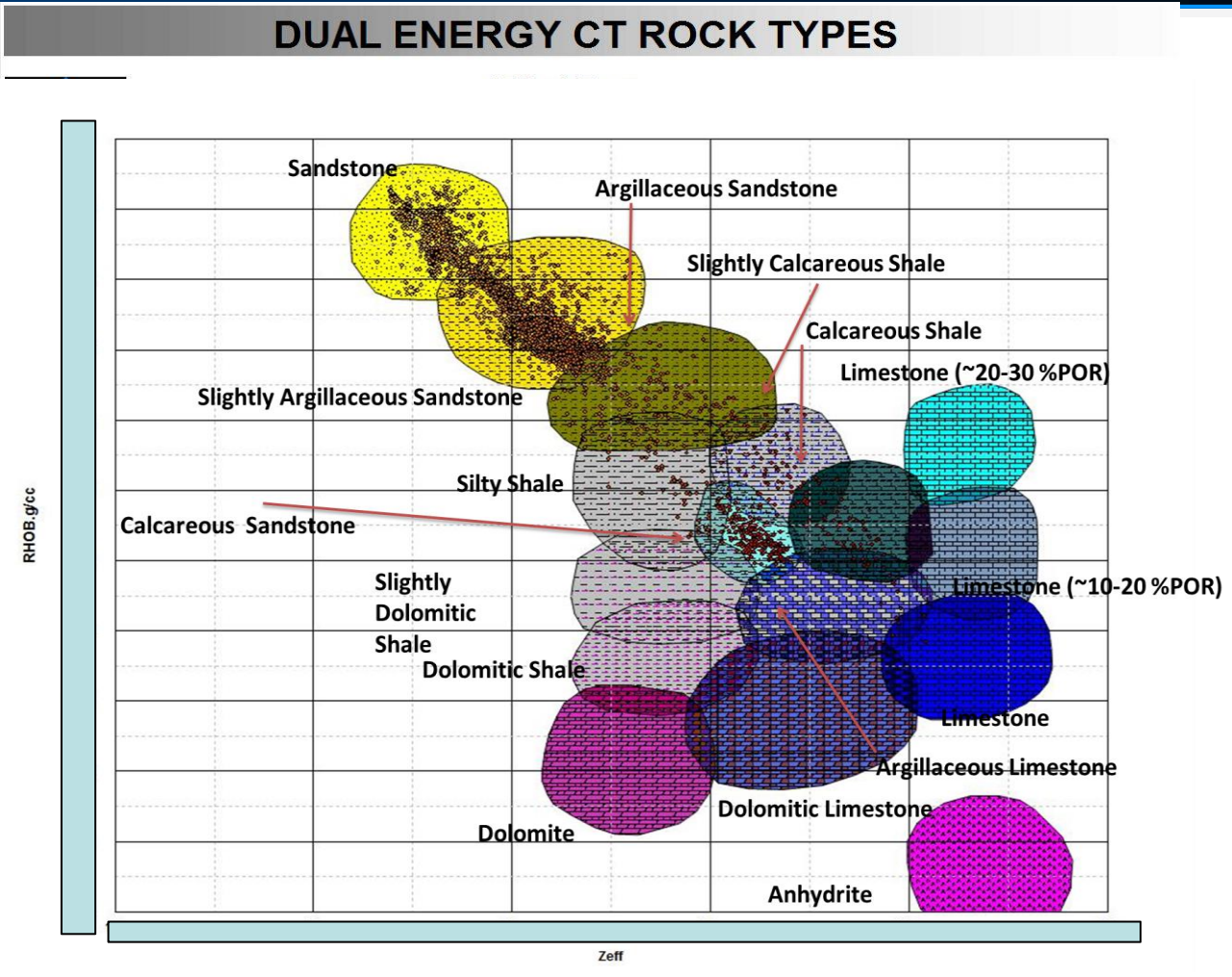


Dual Energy CT – Rhob and Zeff



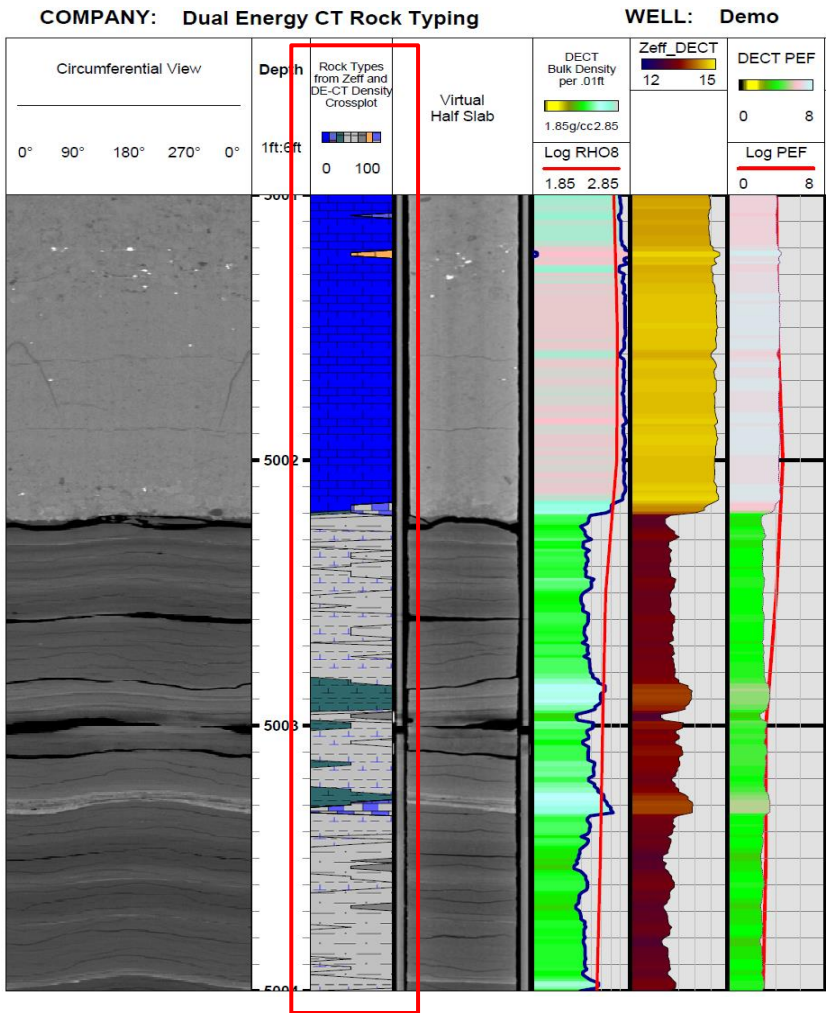
Lithology Clustering, Z_{eff} vs Rhob

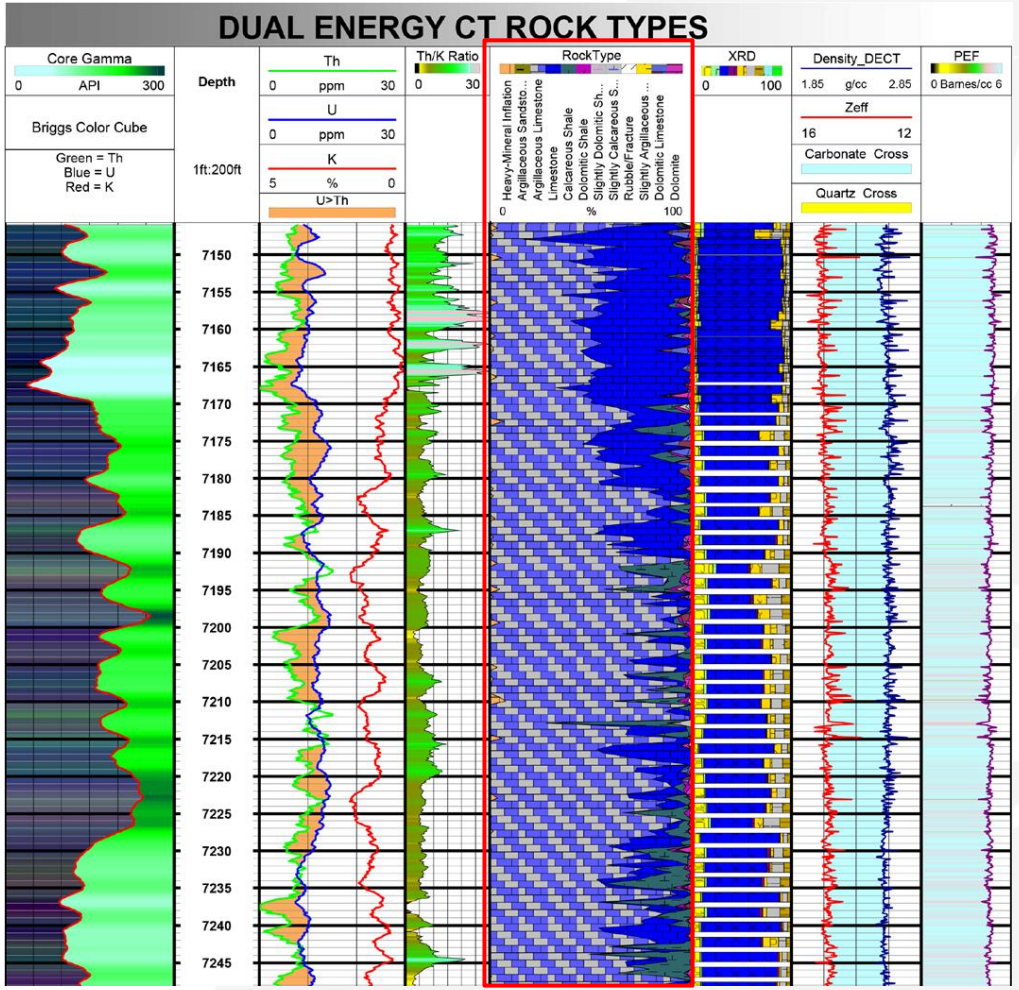




Dual Energy CT

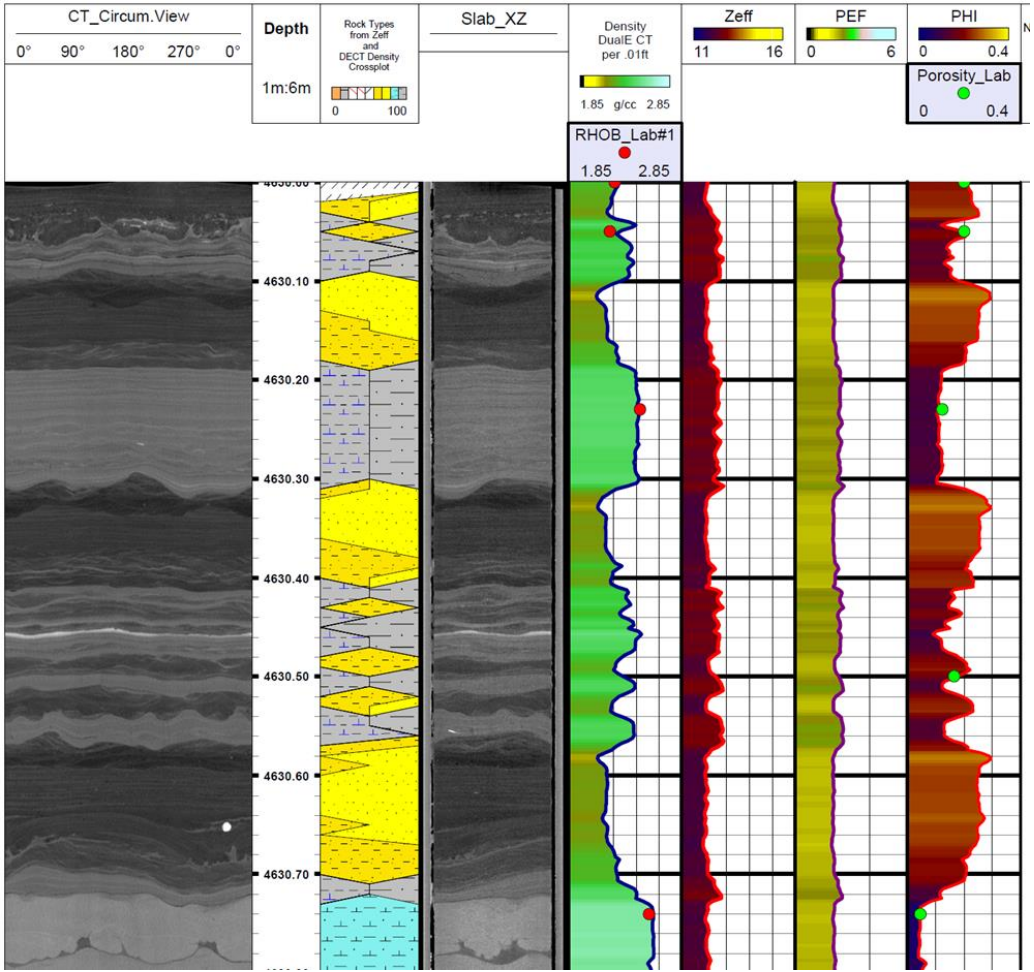
High-resolution Lithology Log





Dual Energy CT

Porosity Estimation



$$\phi = \frac{\rho_g - \rho_b}{\rho_g - \rho_f}$$

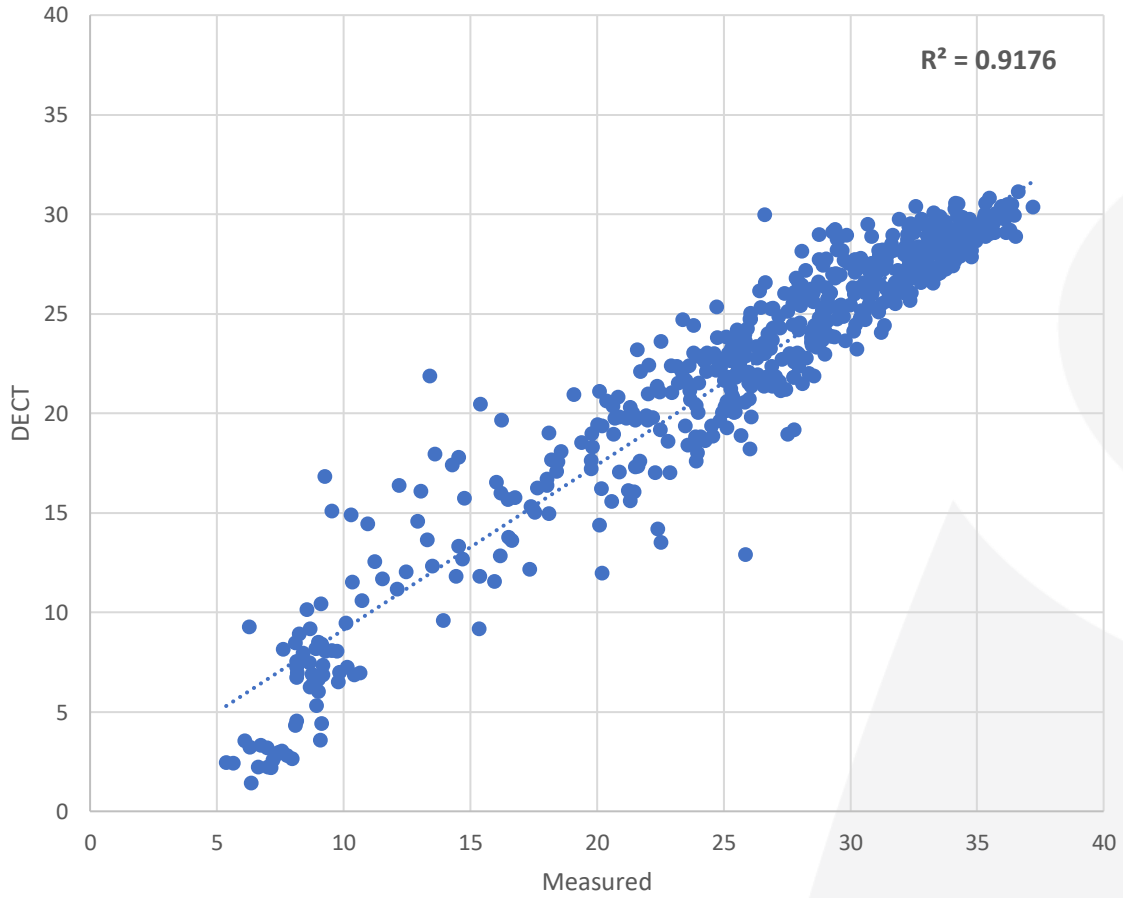
ρ_b = Bulk Density

ρ_g = Grain Density

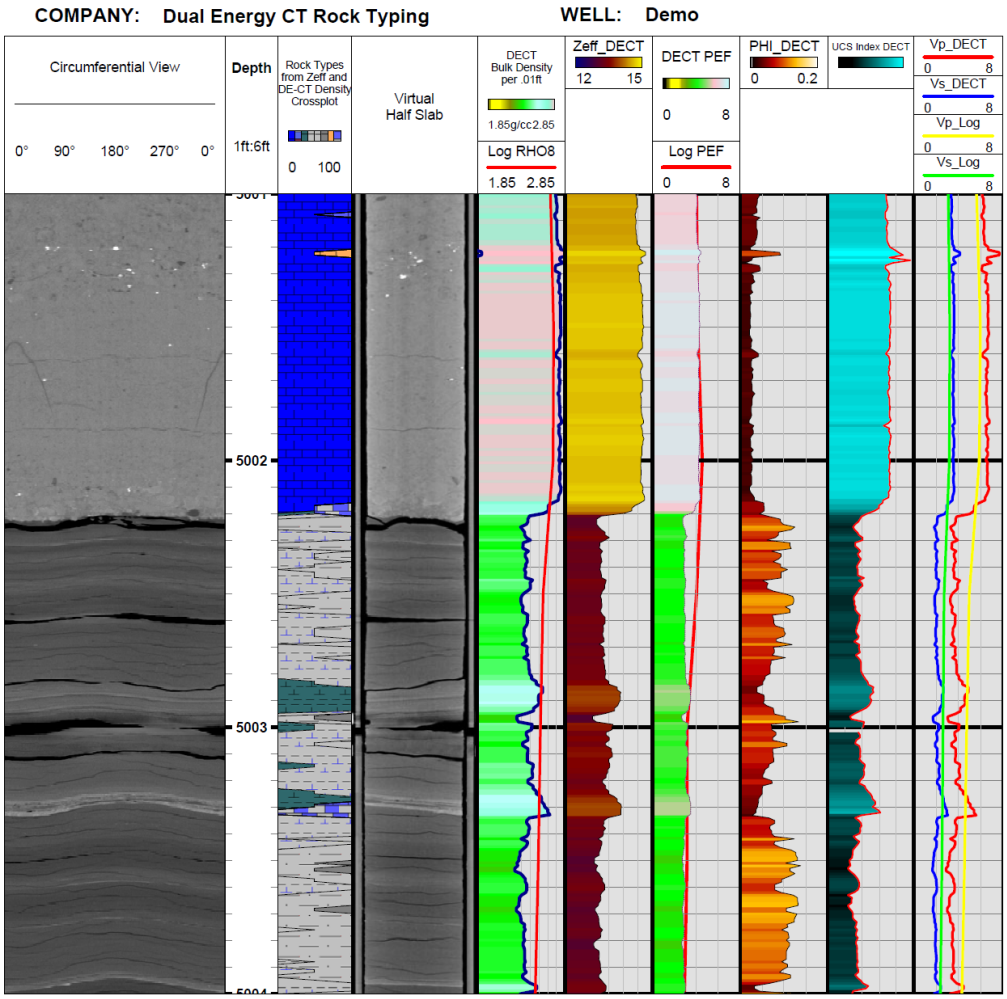
ρ_f = Avg. Fluid Density

DECT

Porosity Calibration with Measured Data



Dual Energy CT Composite Tracks



General Outputs:

1. Density
2. PEF
3. Lithotypes
4. Porosity

Empirical Models

1. Unconfined Compressive Strength Index
2. Acoustic Velocities Vp & Vs
3. Young's Modulus and Poisson's Ratio

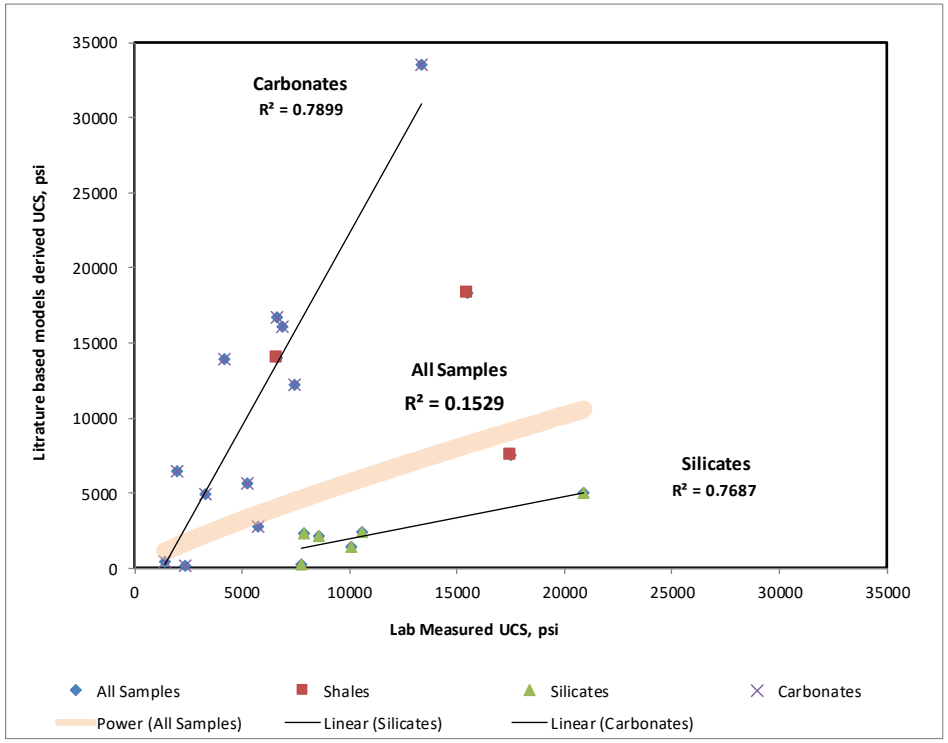
Additional log opportunities

1. Spectral Gamma (Core Gamma)
2. Permeability (PDPK)
3. Mineralog (XRF)

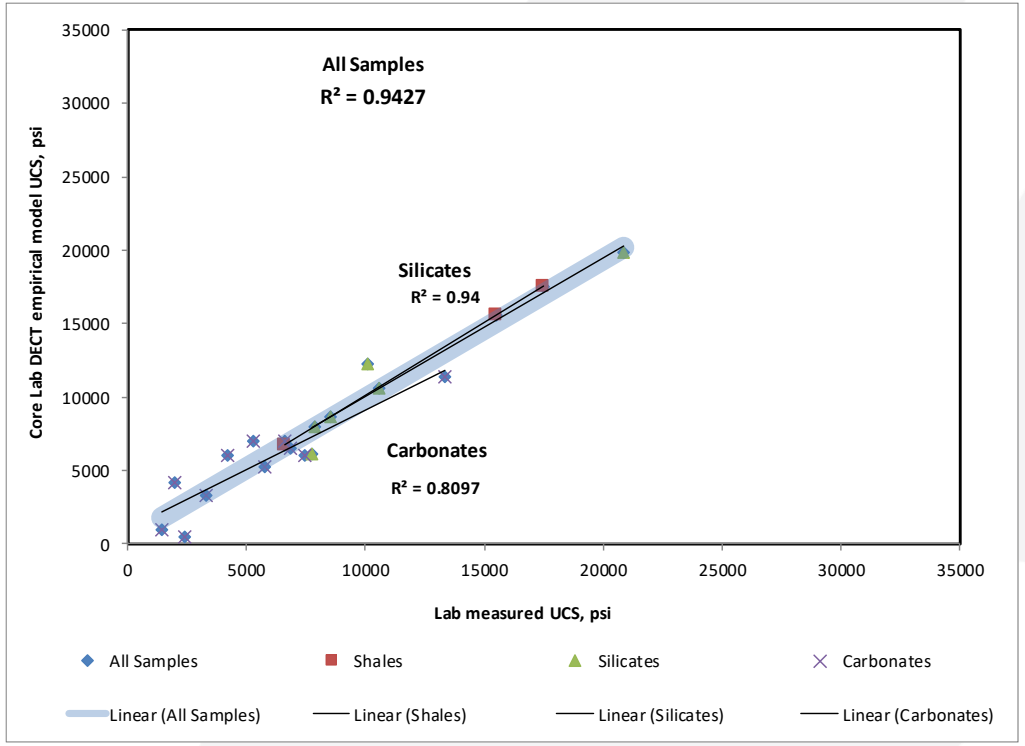
** Data available in 2 weeks from core arrival*

Unconfined Compressive Strength

Models' vs Measurements



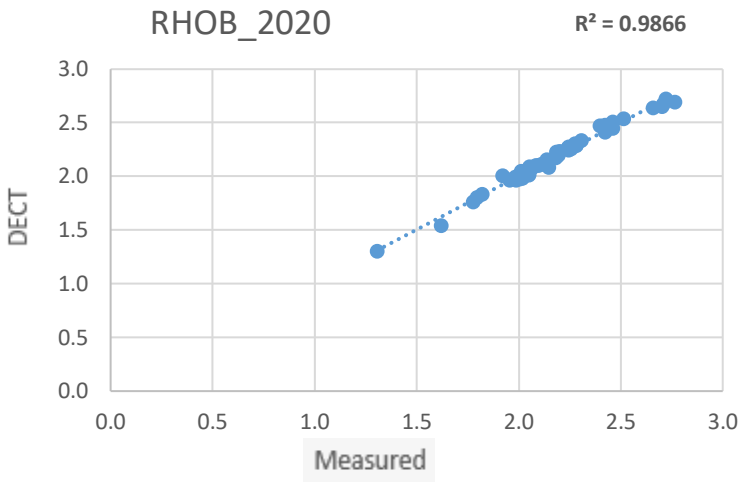
Literature Models
(Porosity and Lithology based)

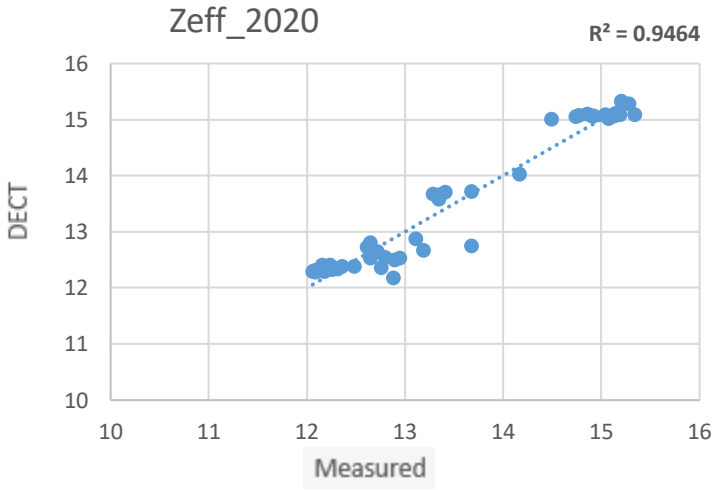


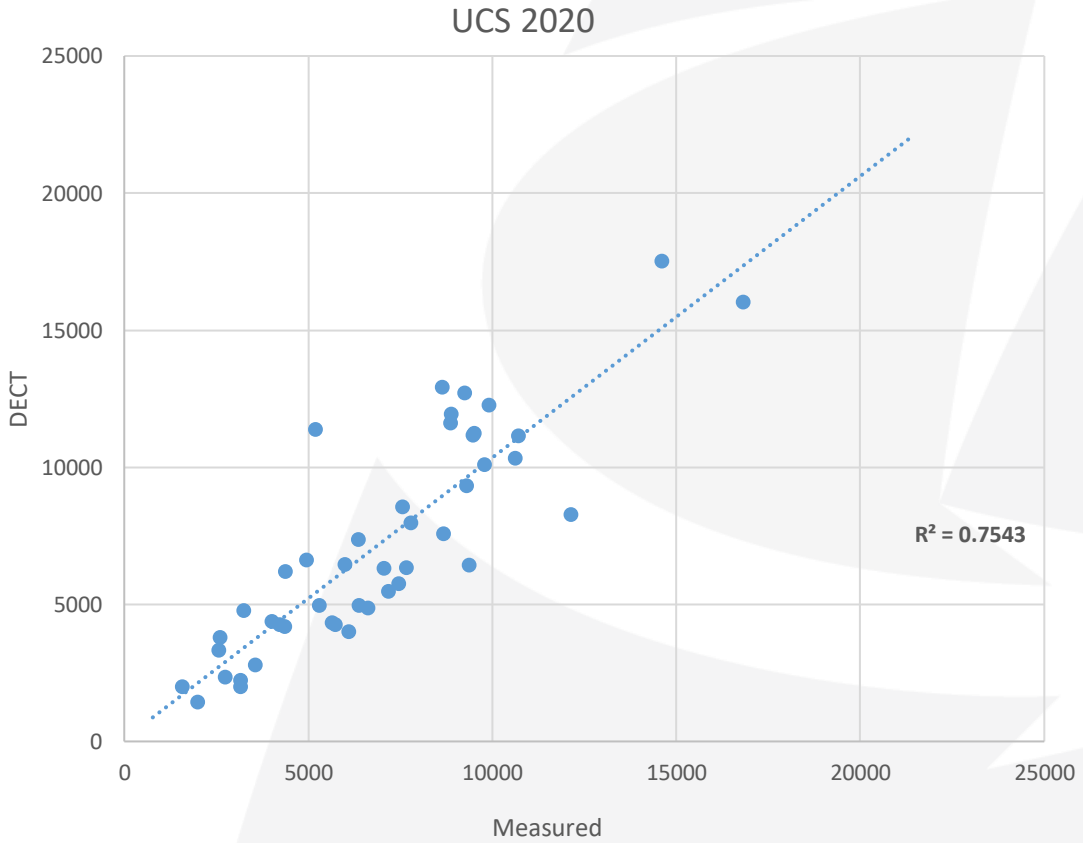
Core-Calibrated Dual Energy CT Models
(Core Lab Proprietary)

DECT

Refined Empirical Models

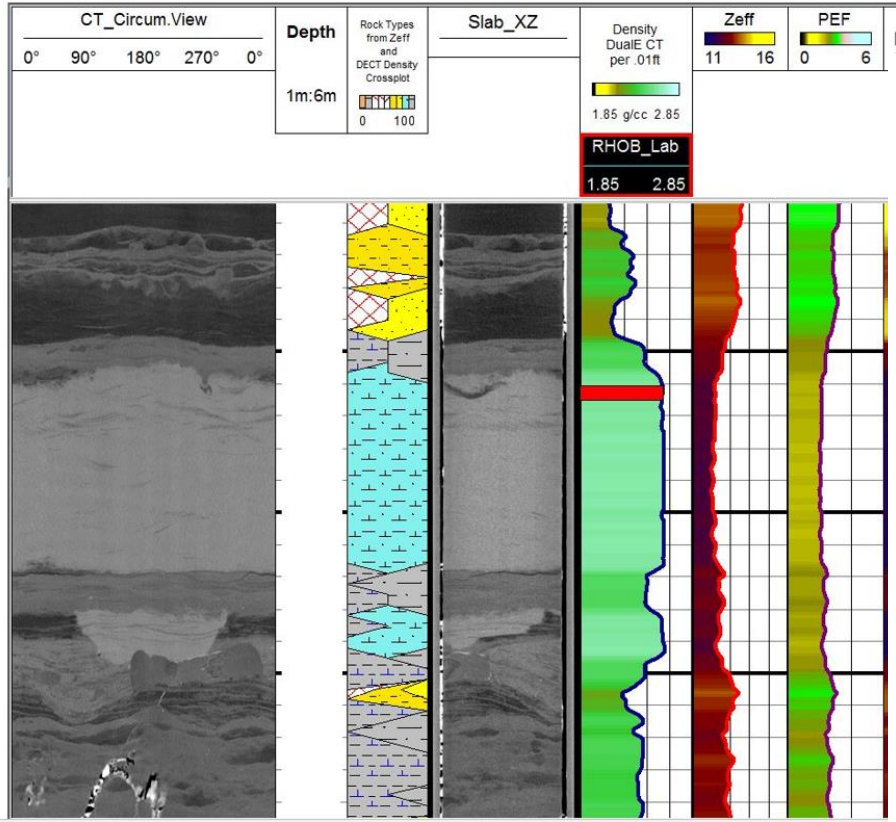


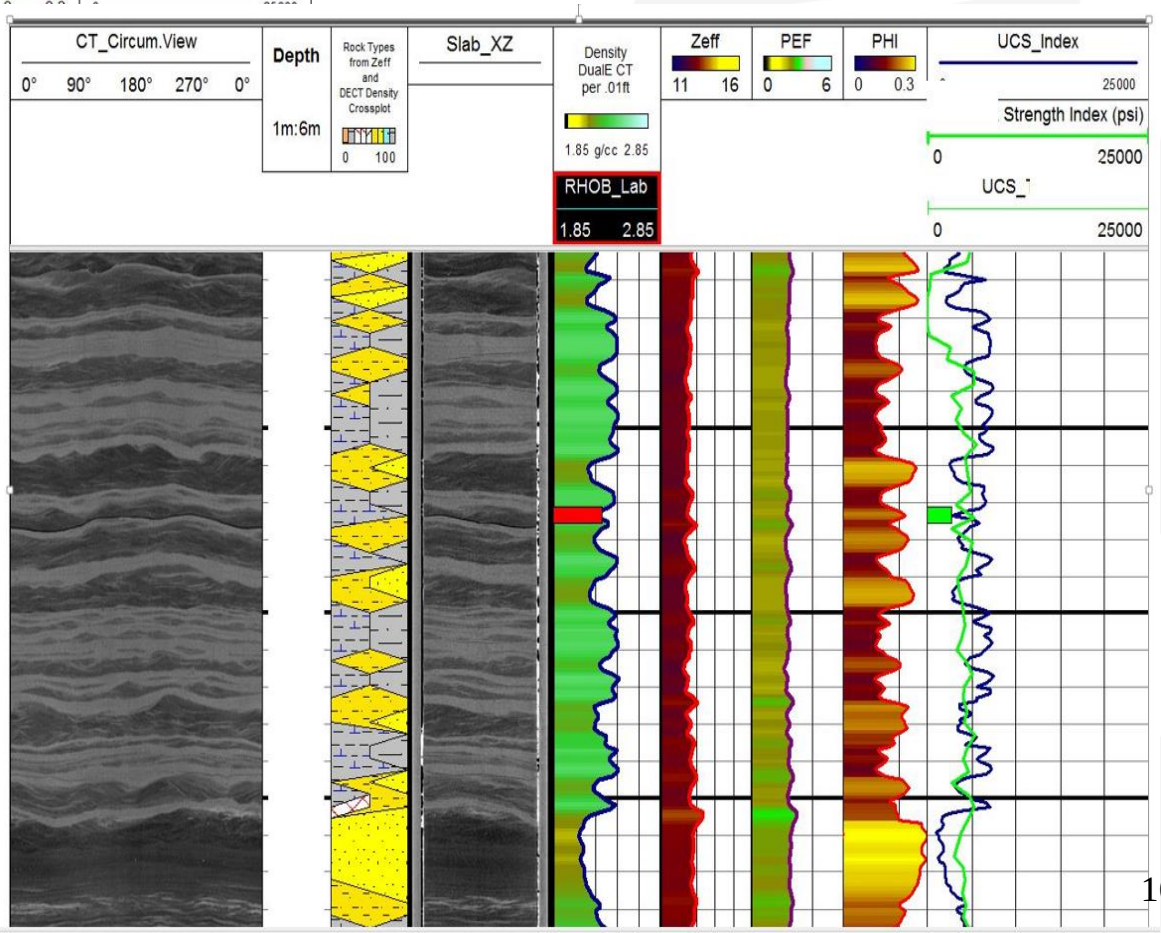




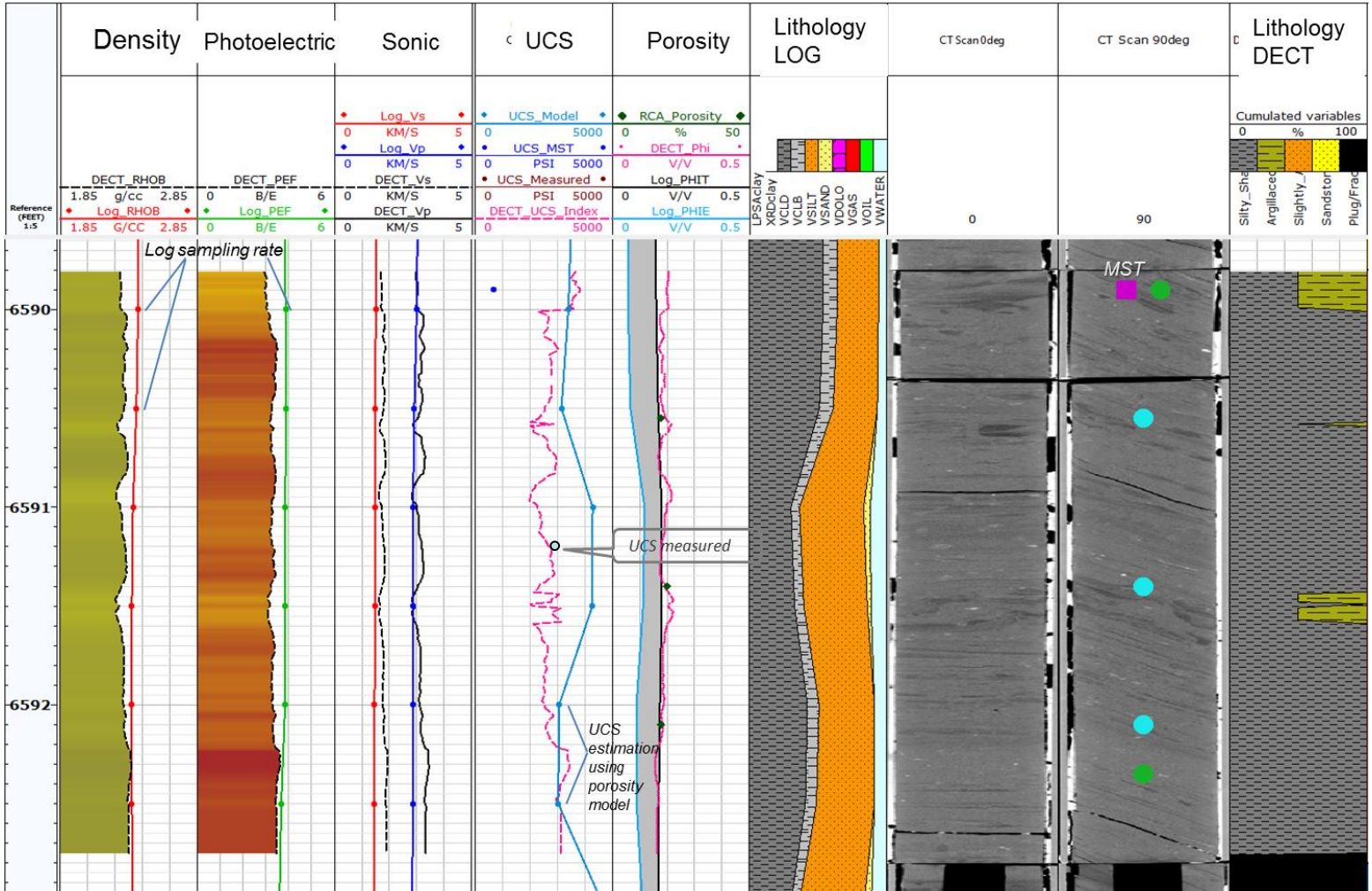
Unconfined Compressive Strength

Core Lab DECT vs Scratch Test

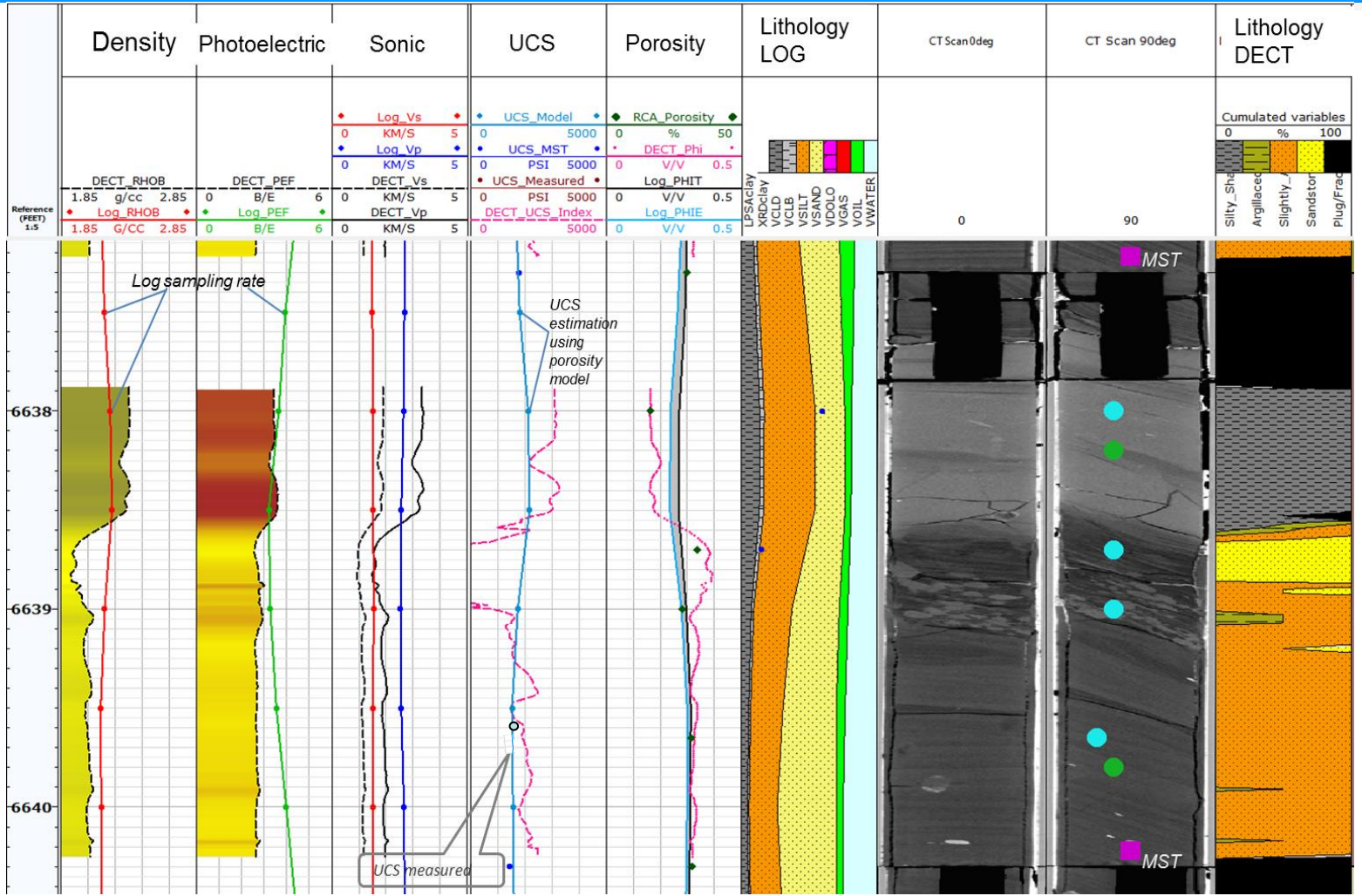




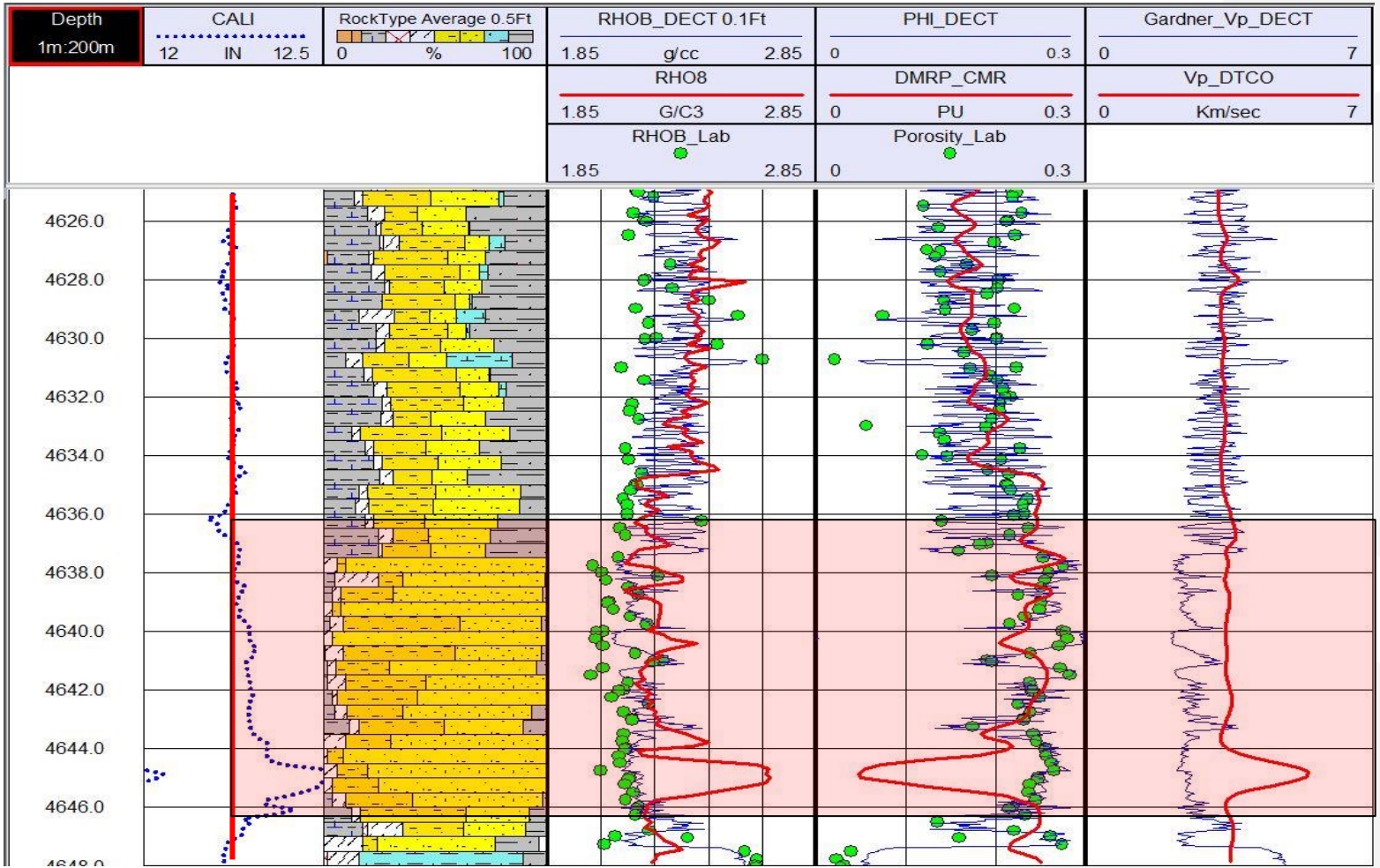
Dual Energy CT - Case Study Example



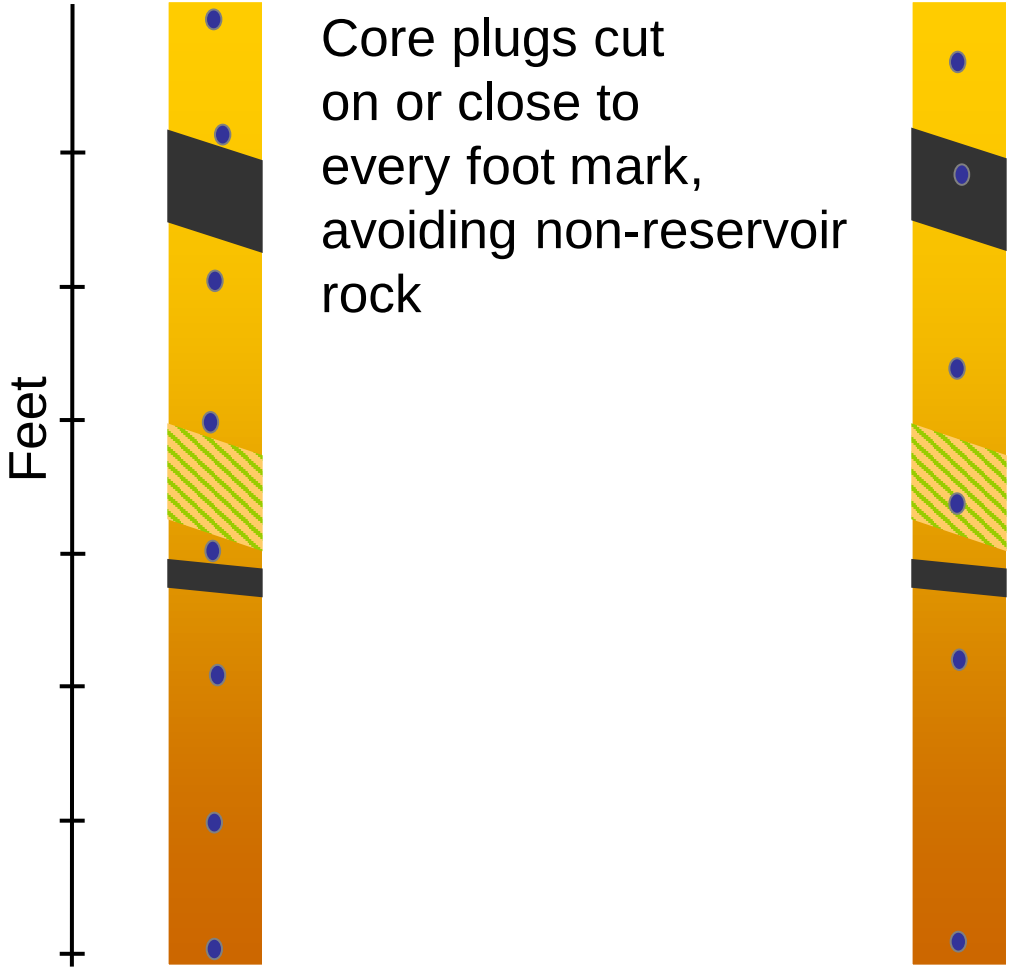
Dual Energy CT - Case Study Example



Log Validation
Challenging Boreholes

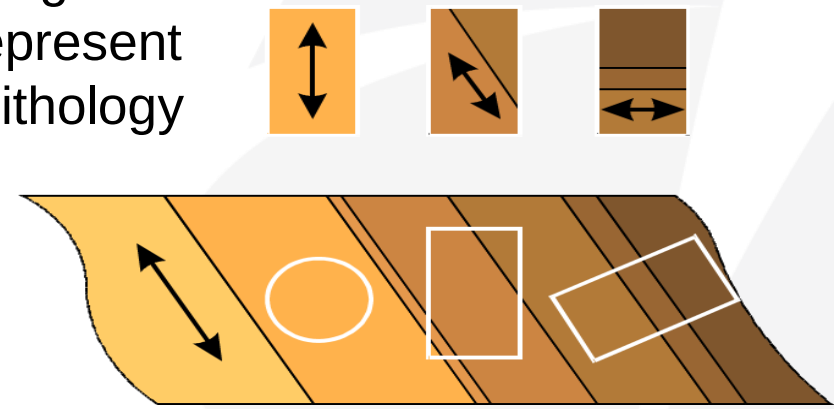


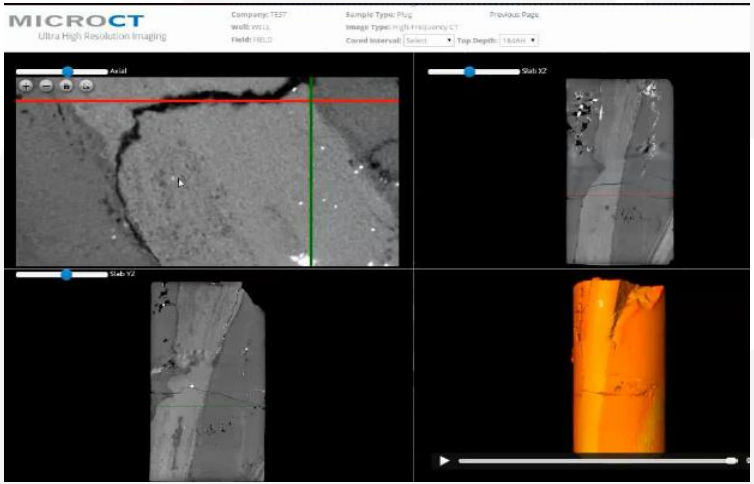
Core Sample Selection



Core plugs cut on or close to every foot mark, avoiding non-reservoir rock

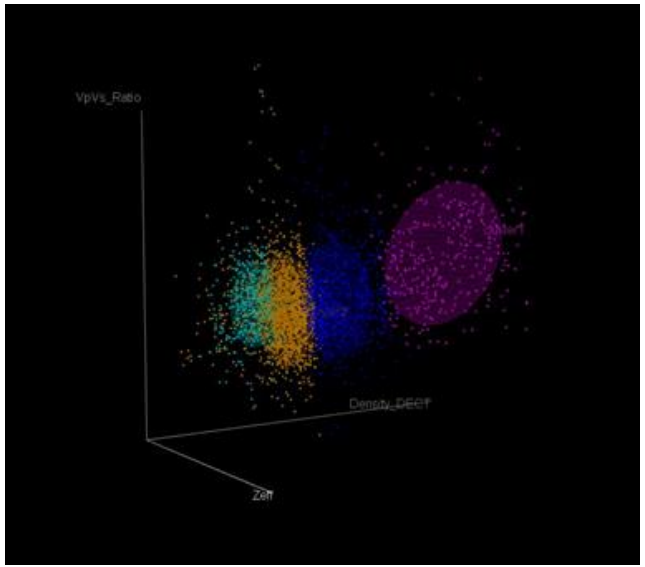
Core plugs cut to represent each lithology



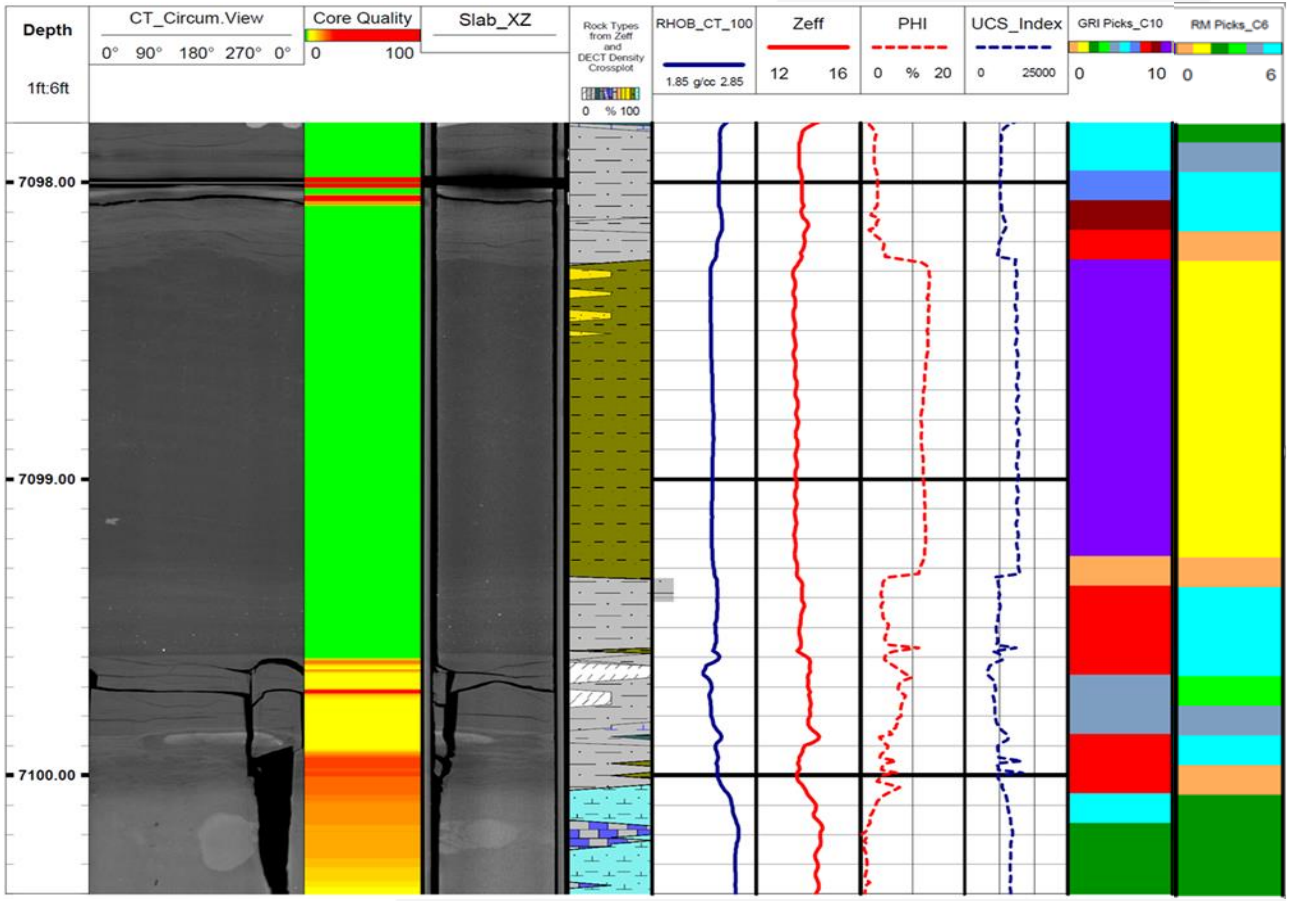


DECT Applications

Automated Sample Selection – ML Clustering



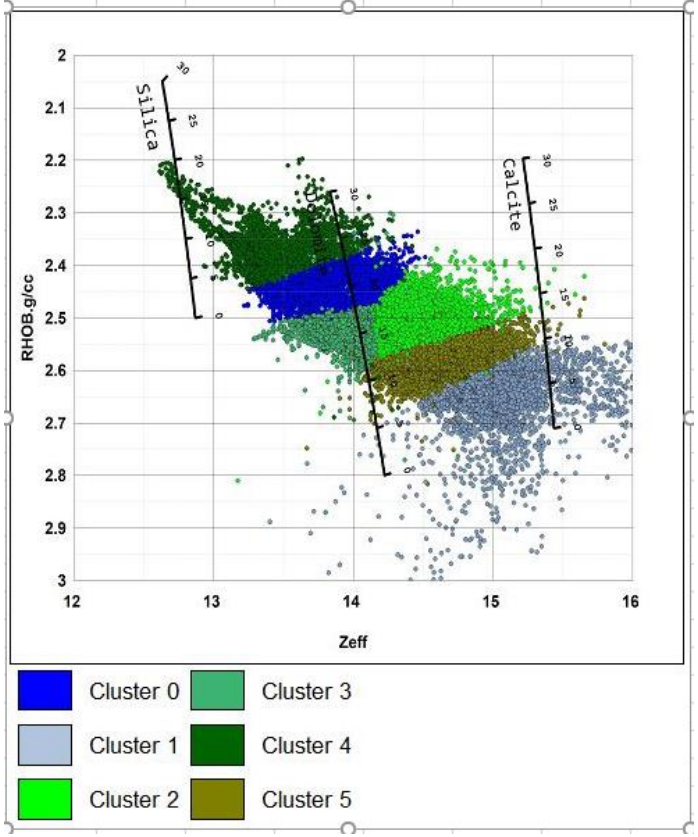
a) Density, Z_{eff}, PHI – **Routine Picks**
b) Density, Z_{eff}, UCS Index - **Mechanical Facies**
c) Z_{eff}, PHI, Ka (PDPK) **- SCAL**

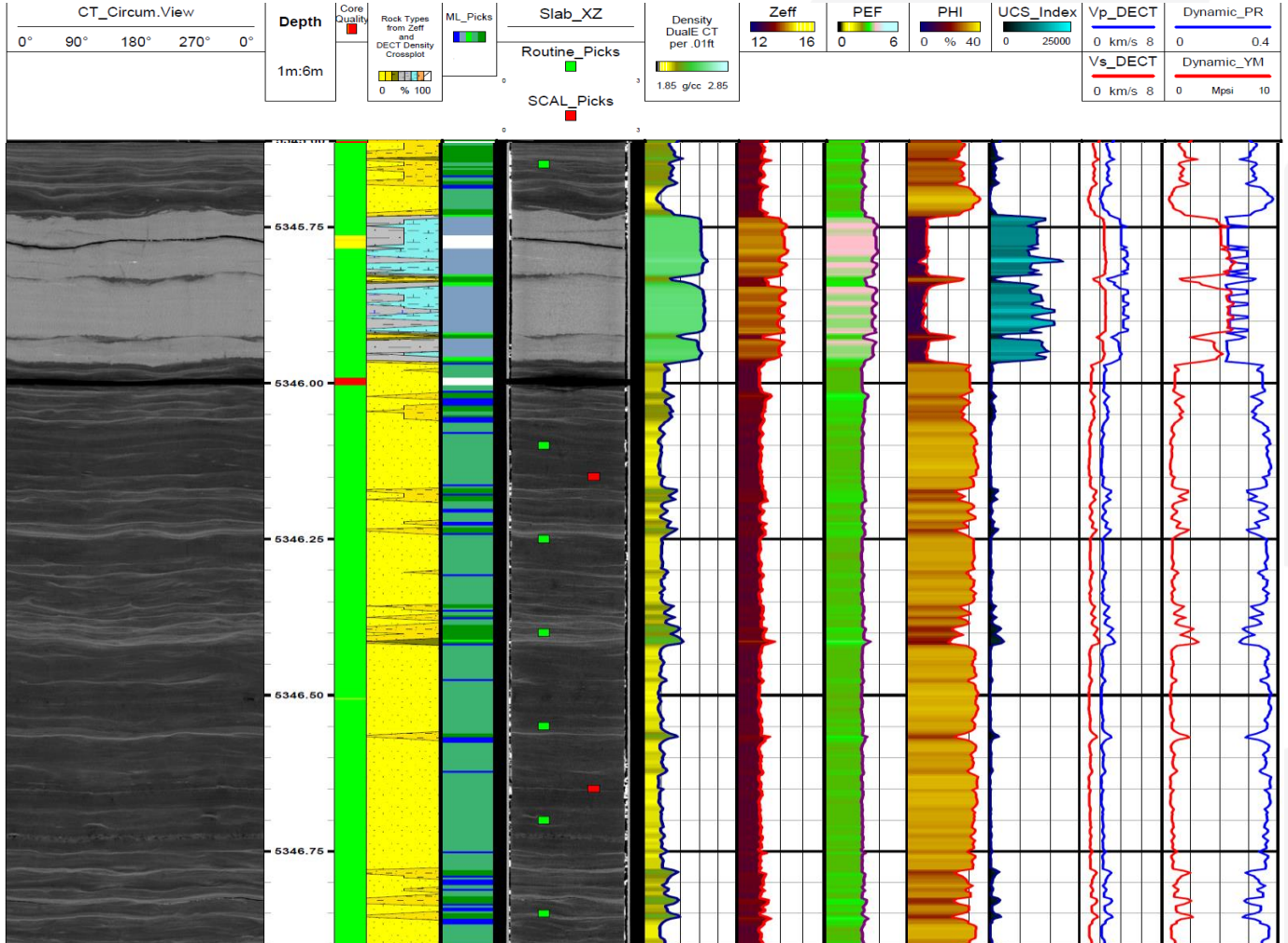


DECT Applications

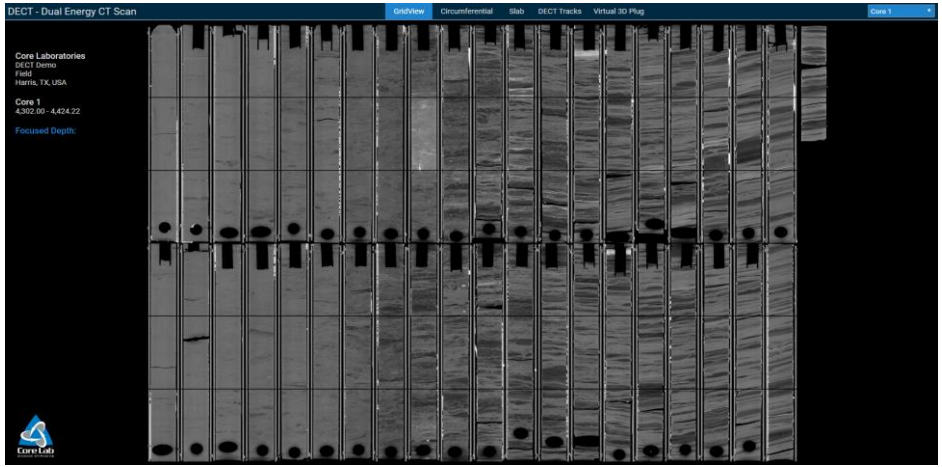
Automated Sample Selection

Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	TOTAL
20	3	13	17	22	25	100
20%	3%	13%	17%	22%	25%	100%

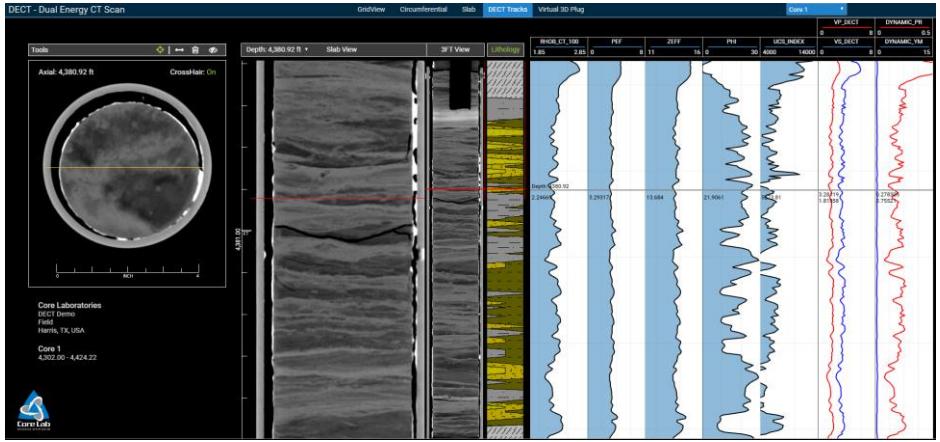




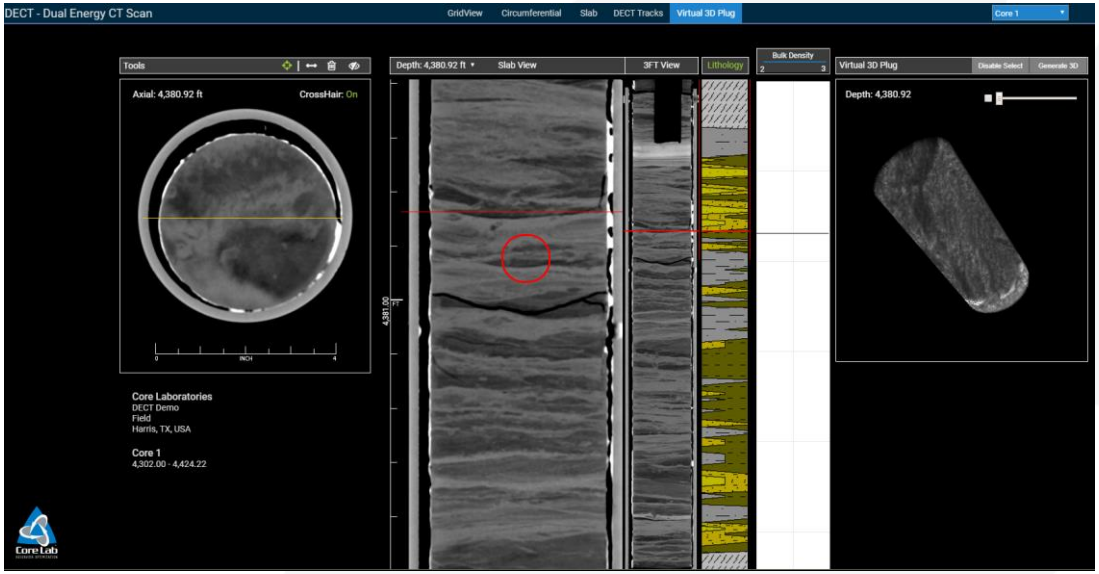
DECT Integrated Browser with VirtualPlug



Grid View

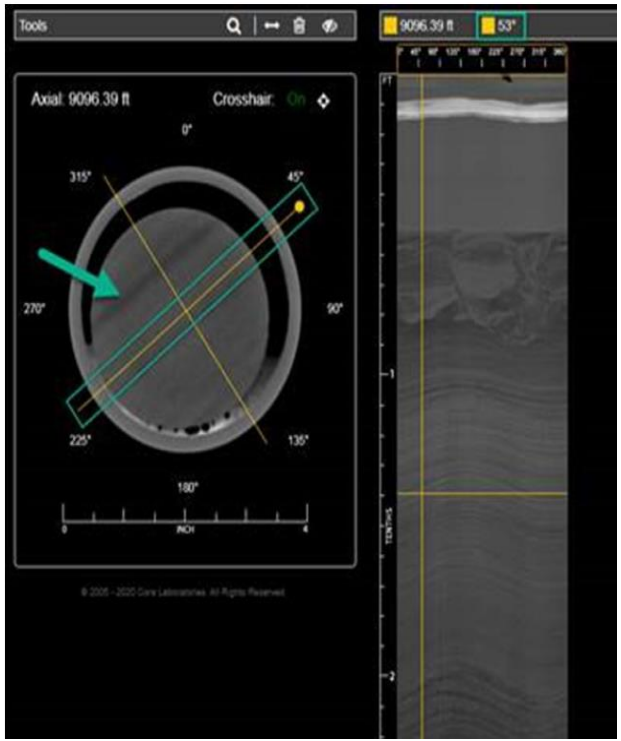


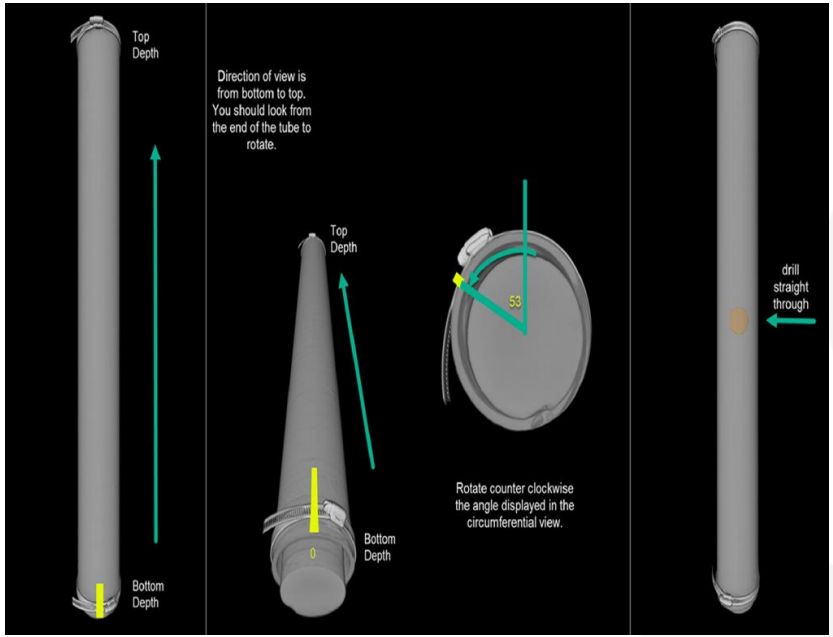
DECT Integrated Tracks

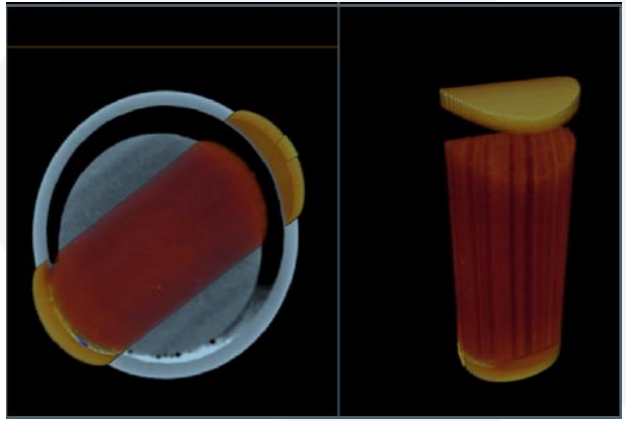


Virtual Plug (Selection)

DECT Virtual Plug

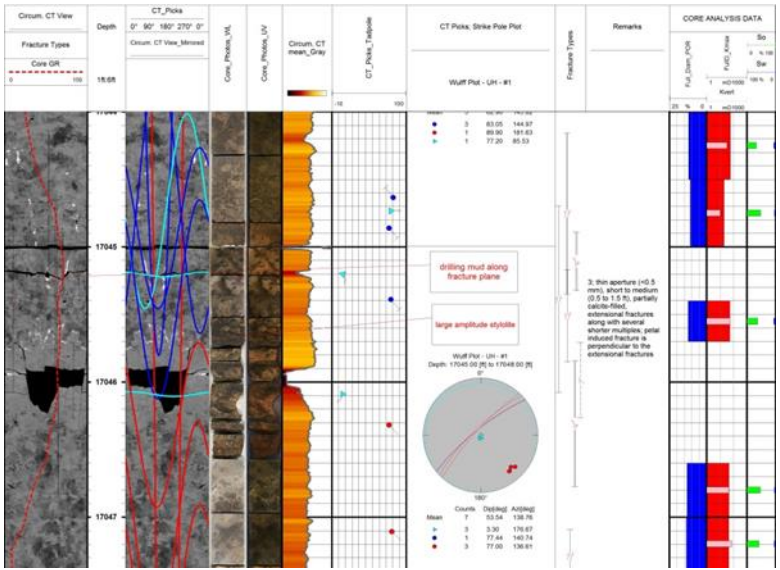


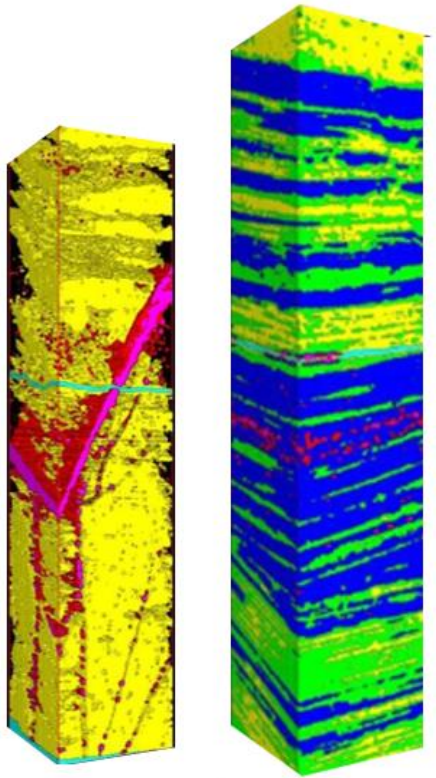


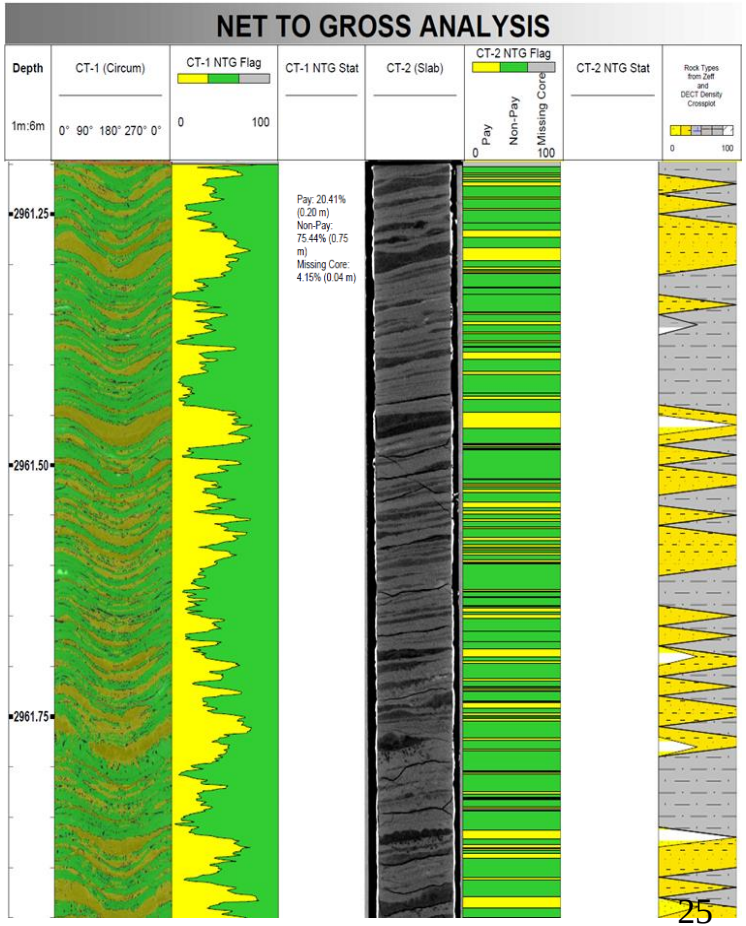


CT Scanning - Other Applications

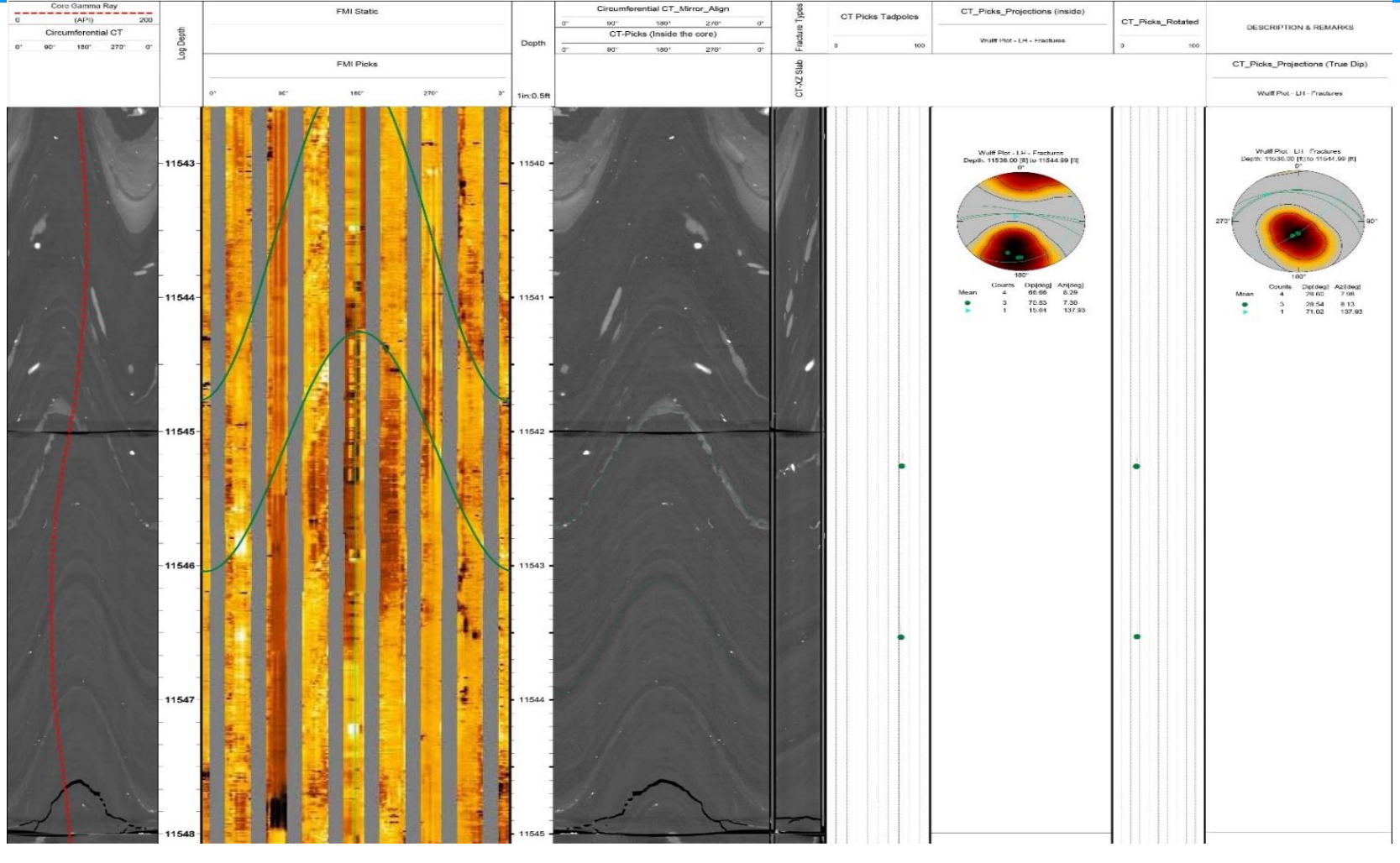
- Fracture Characterization & Density Mapping
- Net to Gross







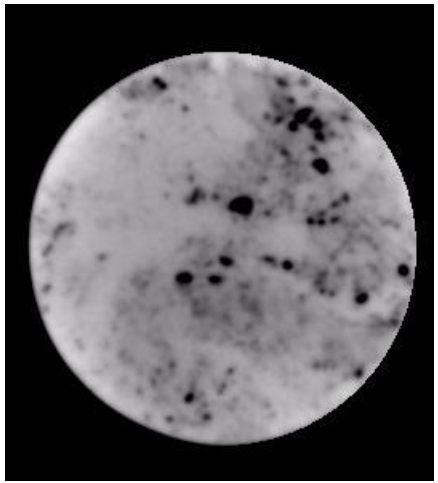
CT Fracture Modeling: Alignment

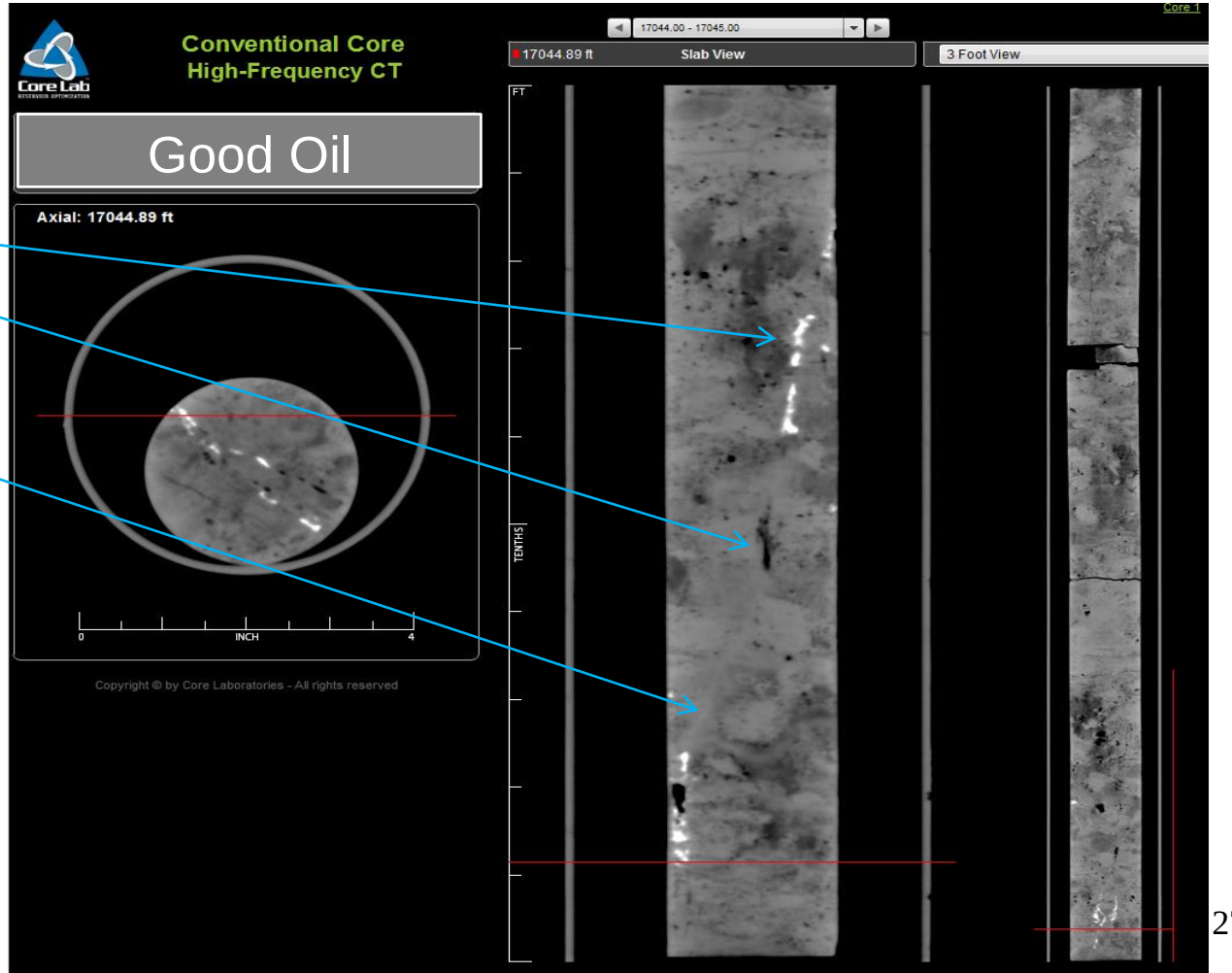


CT Fracture Analysis – Workflow Example

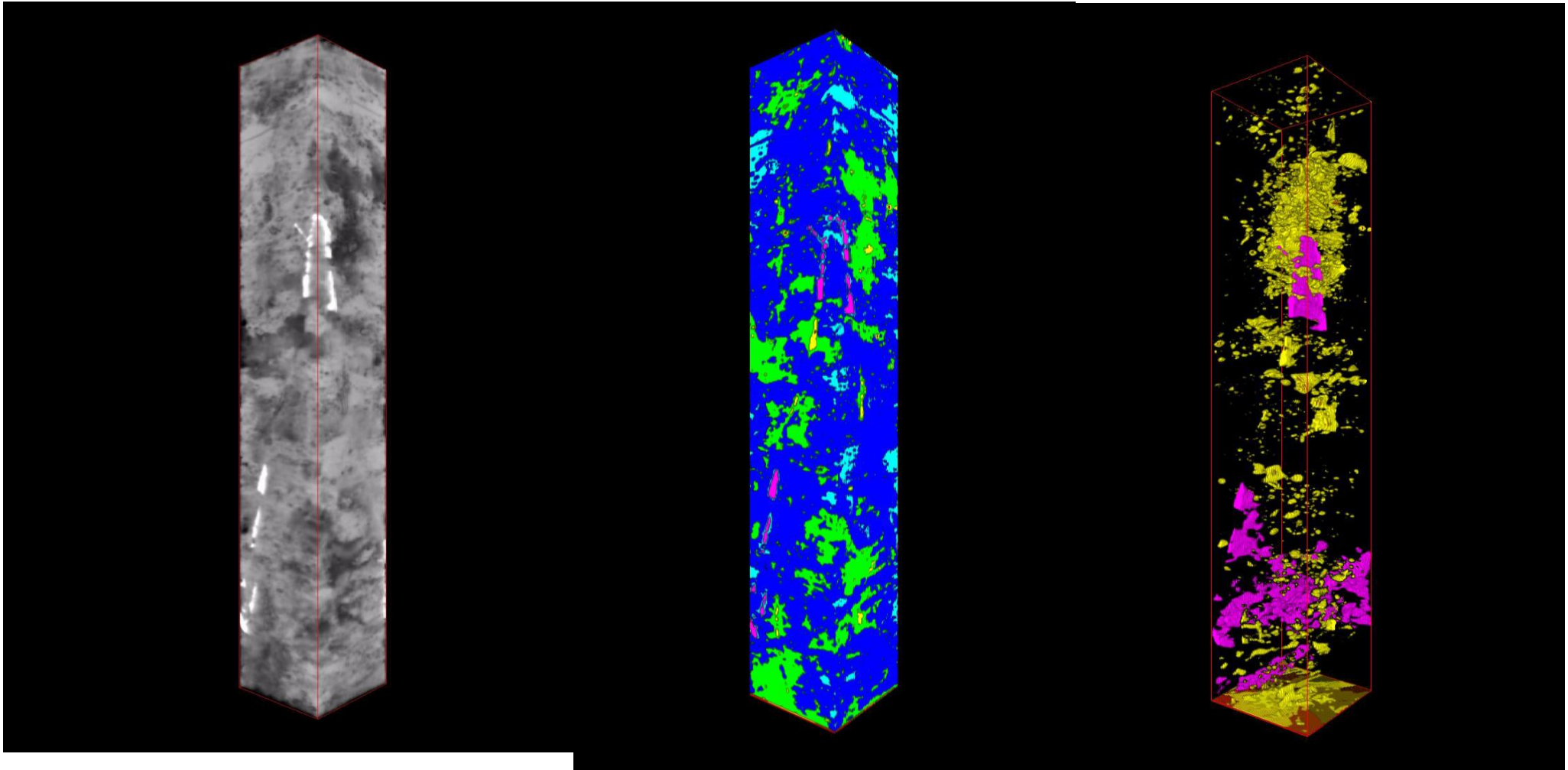
The fractures within the interactive viewer are identifiable by

1) Drilling mud evasion (bright white).
2) Open fracture apertures (black); or
3) Calcite-filled fractures (gray linear features)

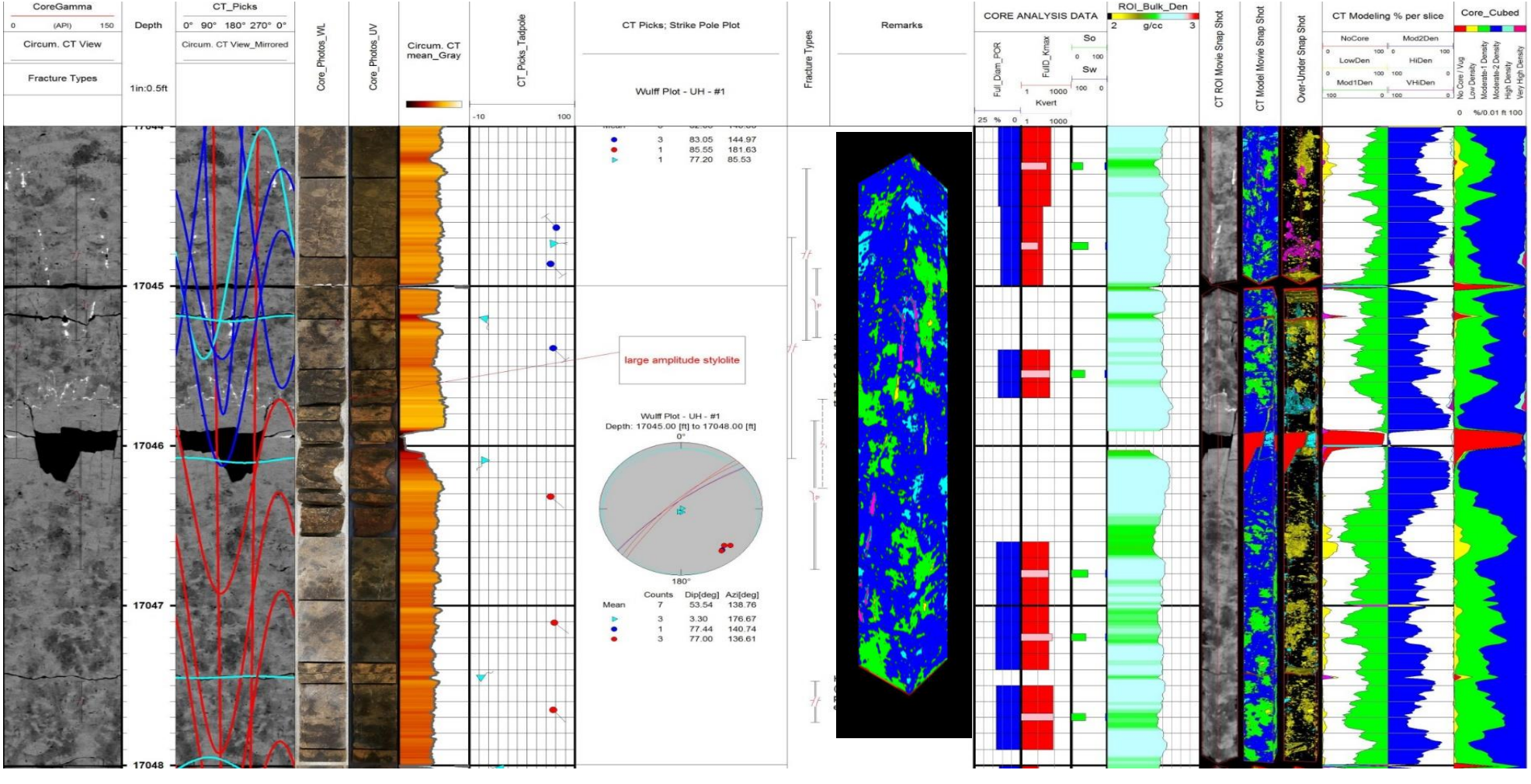




CT Modeling – Density Mapping



CT Density Modeling Panel

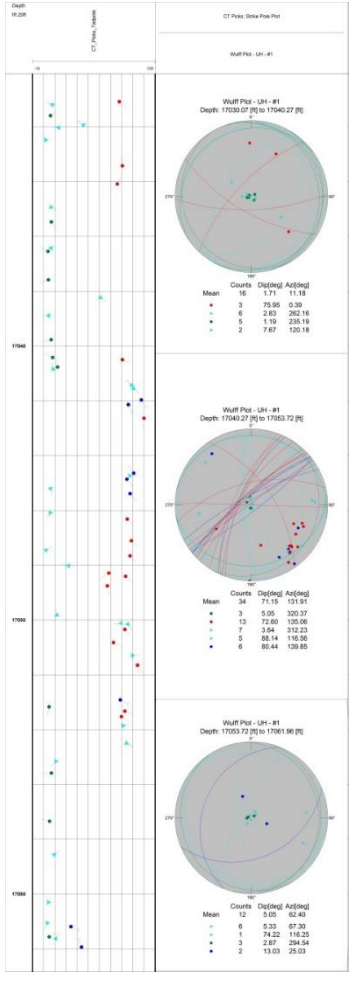


CT Fracture Table

- **Excel file of all the measure fractures (portion of the file)**

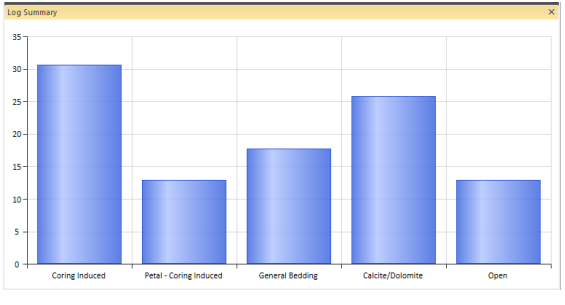
Fracture Table

Depth.ft (top)	Depth.ft (bottom)	Dip Azimuth	Dip Angle	Fracture Aperture .mm	Length.ft	Type of Cement	Type of Fracture	Notes
17044.27	17045.34	182	90	0.2	1.07	Spar calcite	extensional	several short multiples
17044.70	17046.08	322	81	0.15	1.38	partially calcite	open -extensional	
17044.89	17045.32	86	77	n/a	0.43	n/a	petal-induced	
17044.10	17045.20	140	75	0.5	1.10	partially calcite	open -extensional	several multiples
17045.71	17046.27	165	6	n/a			induced	
17044.70	17045.60	141	77	1.1	0.90	partially calcite	open -extensional	several multiples
17045.84	17046.77	209	6	n/a			induced	
17045.80	17046.32	136	75	0.3	0.52	Spar calcite	extensional	
17047.07	17047.40	132	79	0.2	0.33	Spar calcite	extensional	



- **The second worksheet has other summary plots**

	Counts	Dip[deg]	Azi[deg]
Mean	62	18.00	128.39
●	16	74.10	138.02
▷	19	1.42	334.35
●	11	2.29	297.60
▷	8	84.69	118.25
●	8	79.40	139.42

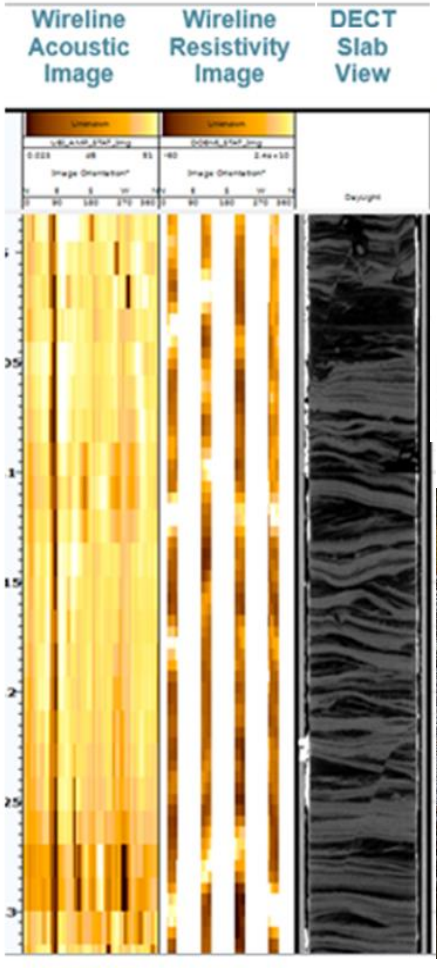


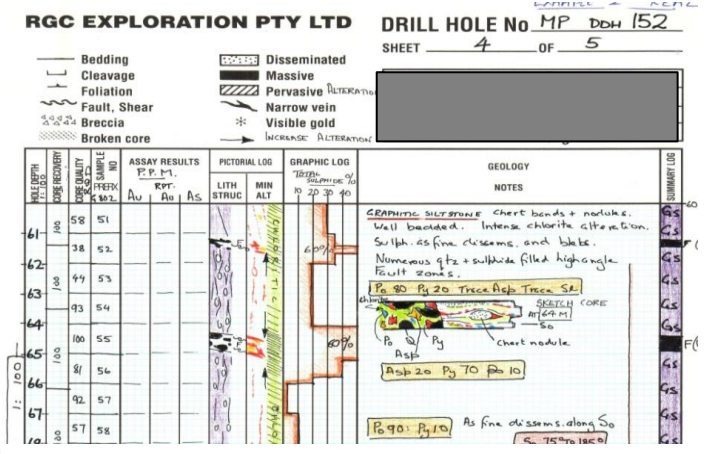
Net to Gross Analysis

Reserves Estimation

$$HIIP = \frac{GRV * N:G * \phi * (1 - S_w)}{FVF}$$

- Petrophysical Cut-offs
- Image logs Analysis
- Conventional Core Description
- Other tools?

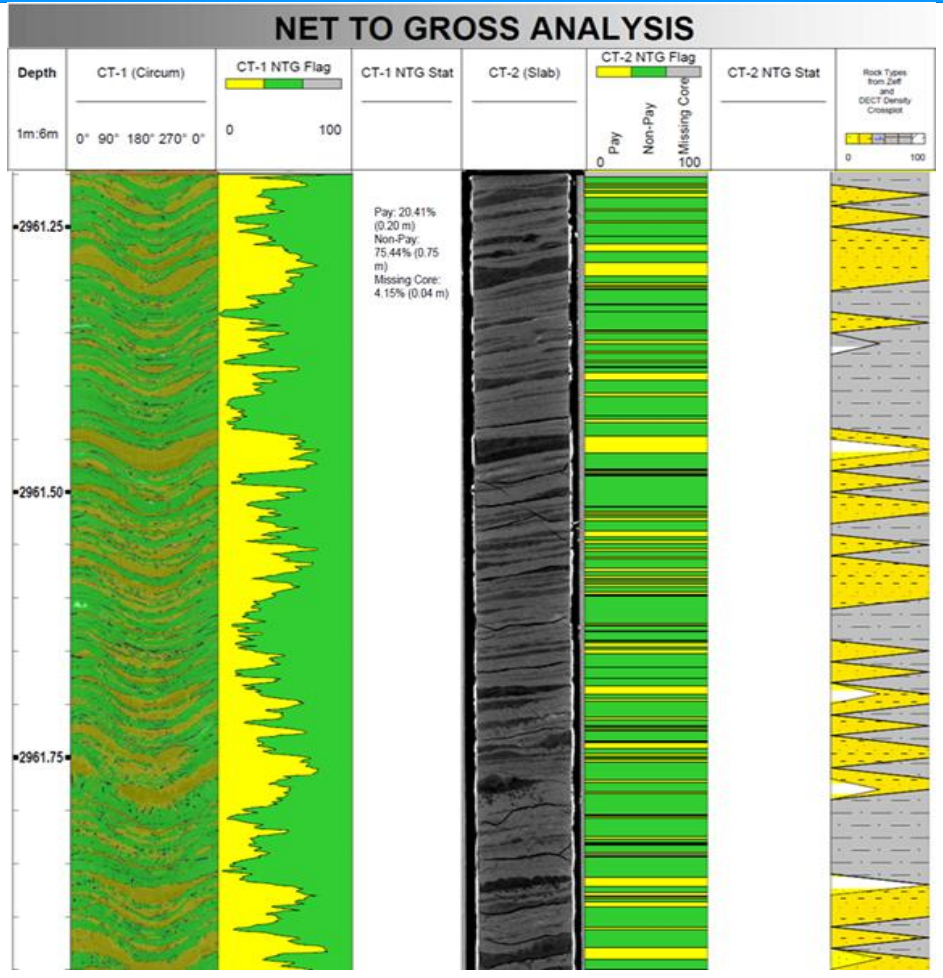


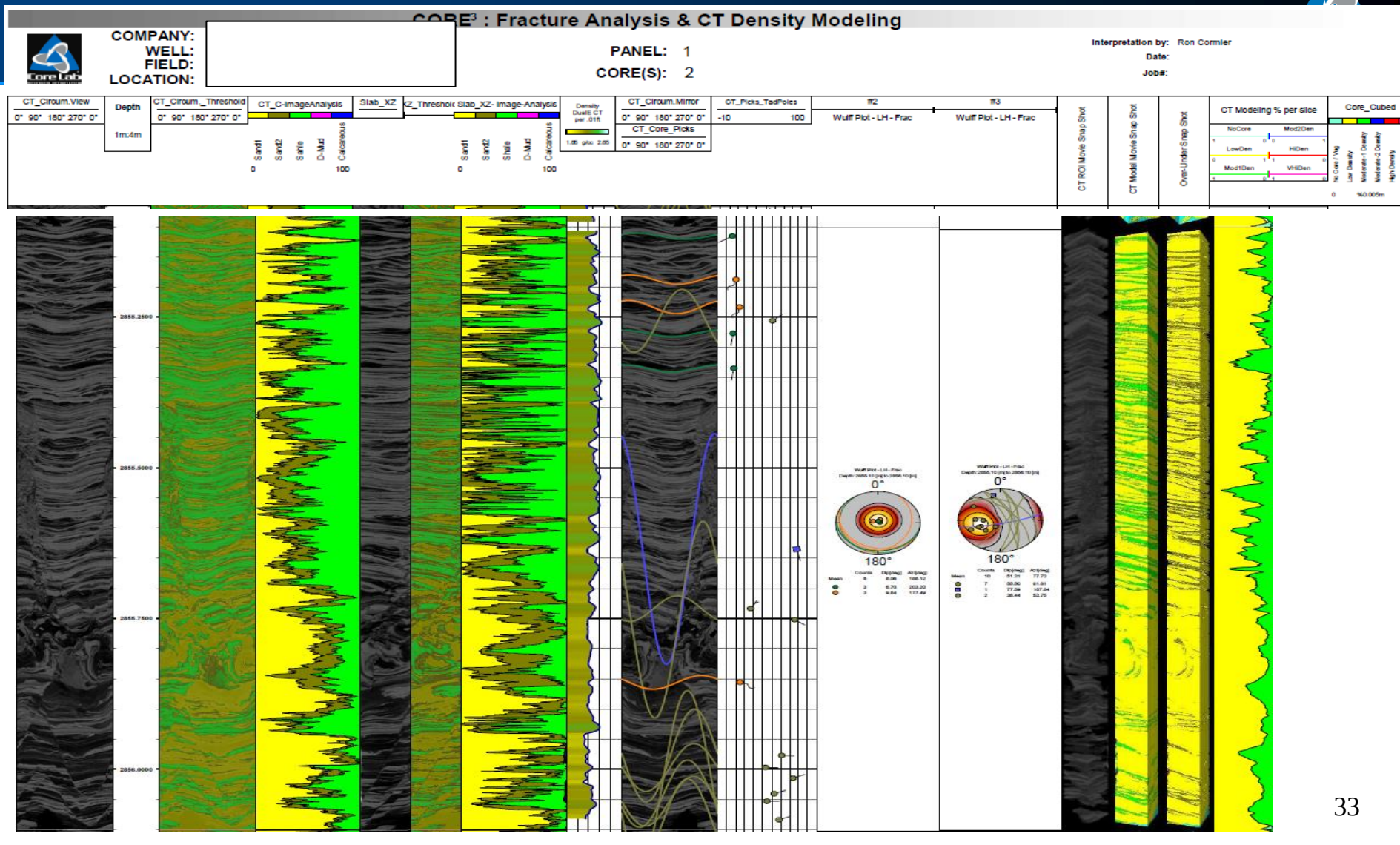


CT Density Modeling - NTG

Why Digital NTG?

- Rapid Assessment
- Density mapping along entire core length
- Consistent & Impartial
- Detailed Interval Statistics
- Large region of interest:
  - Slabs, Circumferences, Full 3D objects




CORE³ : Fracture Analysis & CT Density Modeling
COMPANY:
WELL:
FIELD:
LOCATION:
PANEL: 1
CORE(S): 2
Interpretation by: Ron Cormier
Date:
Job#:
CT_Circum.View
Depth
1m:4m
CT_Circum._Threshold
CT_C-ImageAnalysis
Slab_XZ
Slab_XZ- Image-Analysis
Density
CT_Circum.Mirror
CT_Core_Picks
CT_Picks_TadPoles
#2
Wulff Plot - LH - Frac
#3
Wulff Plot - LH - Frac
CT ROI Movie Snap Shot
CT Model Movie Snap Shot
Over-Under Snap Shot
CT Modeling % per slice
Core_Cubed
Sand1
Sand2
Shale
D-Mud
Calcareous
2858.2500
2858.5000
2858.7500
2859.0000
0°
180°

Why CT Scan Cores?

- Quick Turnaround Times
- Digital Preservation of Core For Life
- Rapid Petrophysical Data
- Optimized Sample Strategy
- Better Core Analysis Program
- Reduced Uncertainty
- Interactive Fracture Analysis for better reservoir Network Modelling
- Dual Porosity system characterization
- Rapid, impartial and consistent NTG analysis